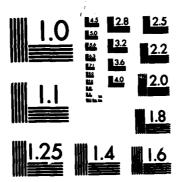
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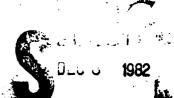
PROTOTYPE DECISI SUPPORT SYSTEM

THE LOCATION OF MILITARY WATER POINTS

bу

Monty Joseph Anderson, CPT EN

June, 1980



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PROTOTYPE DECISION SUPPORT SYSTEM

FOR

THE LOCATION OF MILITARY WATER POINTS

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Monty Joseph Anderson, CPT EN

June, 1980

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# PROTOTYPE DECISION SUPPORT SYSTEM

**FOR** 

# THE LOCATION OF MILITARY WATER POINTS

## A THESIS

Presented to

The Faculty of the Division of Graduate Studies

bу

Monty Joseph Anderson

In Partial Fulfillment
of the Requirements for the Degree
Master of Science in Operations Research

Georgia Institute of Technology

June, 1980



Letter onfile

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# SUMMARY

A demonstration prototype Decision Support System (DSS) has been developed, documented, and validated for interactive selection of water supply point locations by the U.S. Army Division Engineer.

The DSS aids the user in digitizing, from a map, a network having nodes at each possible supply point, each possible customer (combat unit) location, and each relevant crossroads, with distances automatically entered as roads are traced. It also assists in providing and revising problem-specific data on demands, supplies, and customer locations. It aids in performing an interactive optimization procedure based on the location-allocation optimization model to identify efficient solutions, in investigating the consequences of uncertainties or changes in data, and in the integration of considerations not reflected in the location-allocation formulation, e.g., factors not practically quantifiable such as mission, enemy, terrain and command guidance.

The prototype operates in stand-alone mode (no host computer) on the experimental DSS vehicle currently being used in DSS research by the U.S. Army Computer Systems Command: A Chromatics CG-1999 color graphics system with light pen, digitizer, 64K memory, and dual or single floppy disk drive. The prototype is ready for initial user testing.

Although the input and output of the prototype are specific to water point location analysis, the system also constitutes a prototype for interactive solution of location-allocation problems in general.

# DECISION SUPPORT SYSTEM A PROTOTYPE

FOR THE LOCATION OF MILITARY SIMO BUILS

#### CHAPTER I

#### INTRODUCTION

The usual availability of pure water in a peacetime environment is often disrupted during combat. Battles may be fought in deserts or in areas whose water resources have been contaminated or made unavailable. In developed areas a high probability exists that the civil administration and supporting services will be severely disrupted by combat. Historically, water, waste disposal, and sewage systems have been seriously degraded by combat activities. Should chemical and/or biological weapons be employed, providing potable water would be of even greater concern. Definite procedures have been published to guide U.S. Army Division Engineers in providing fresh water to units under Division control.[18] See Appendix VII.

The purpose of this research is to provide a prototype of a Decision Support System (DSS) for the Division Engineer. It will assist him in selecting, from among the potential water resupply sites, those sources that minimize total resupply travel distance consistent with conditions and requirements.

This Decision Support System, subsequently referred to as DSS, is not intended as the ultimate tool for locating logistical facilities on routes of communication. It does permit the lower level manager to make use of existing operations research techniques in the solution of everyday problems. No prior knowledge of operations

research is required. By permitting and encouraging human interaction in the selection process, all of the previous knowledge and experience of the logistician can be supplemented.

# Criteria for Water Point Site Selection

It is necessary to keep in mind that this DSS is not intended to make the actual selection of the best logistical facility locations, henceforth referred to as water points. This is too complex a problem to build a mathematical model of without requiring the input of excessive amounts of data. Presently, only the human mind is capable of assimilating all of the criteria considered in selecting locations.

The criteria considered by the logistics officer[18] in making his decisions are many. If the current tactical situation calls for defensive operations, then the defense and survivability of the water points may be of paramount importance. This is particularly true if there is insurgent activity behind the FEBA(Forward Edge of the Battle An offensive scenario may call for the supported units Area). involved in the attack to receive priority so as to reduce their required resupply effort compared to other units. The threat of nuclear warfare may make dispersion the most important criterion for choosing locations. See also Appendix VII. The fluid nature of modern warfare does not permit the input of large amounts of supporting data.

This DSS is a prototype to demonstrate how operations research

techniques can be implemented on advanced computer graphics equipment. As implemented, this DSS aids the user in selecting sites while minimizing the resupply effort required. All other considerations are taken into account by the human intervention into the selection process. Throughout the remainder of this thesis, these selection criteria will be referred to by the key words: mission, enemy, terrain and command guidance.

# Historical and Military Perspective

Logistical decision makers in the military are inundated with factors, criteria, checklists and immediate command guidance when selecting resupply point locations. In spite of the large amount of work done to define what is important in the siting of logistical facilities, the decision maker currently has few resources other than his mental capabilities with which to make his selection or evaluate subjectively the various alternatives.

The increased lethality and resulting destructiveness of warfare has placed greater demands than ever before on the supply system.

As one of the consequences it is desirable to make the resupply effort
as efficient as possible while providing essential support to the tactical commander. One readily available area for improving efficiency
is in shortening the distance traveled by both the supported units to
get needed materials and by the combat service support elements in
maintaining their stockages. By locating these resupply facilities in
such a manner as to minimize necessary travel, both the time delay
response to demands and the strain on resupply equipment are reduced.

In an Army division, a force of over 15,000 personnel, the Division Engineer is responsible for providing potable water. This responsibility consists of identifying the potential sites and developing the sites as necessary in order to insure access. [18] Access is required for both the engineer operated water purification equipment teams and the supported units who transport their respective water requirements.

The transport of potable water is normally accomplished by the supported units utilizing trucks to pull the standard 400 gallon capacity water trailer. [49] The number of these trailers available to the unit varies depending upon its authorized personnel strength. This number is not a significant factor in this study since only one trailer at a time may be towed by a  $2\frac{1}{2}$ -ton truck or its equivalent. This necessitates one round trip distance being traveled by the unit for each 400 gallon trailer of water consumed. A round trip is defined to be the distance traveled from the current location of the unit to a water point and back by the shortest route.

The water purification equipment authorized for the engineer units who operate them is the 1500 gallon-per-hour truck-mounted unit with 7,500 gallons of on-site storage capacity. [49] The water purification equipment sets have no water delivery capability. Each division has five of these equipment sets. This authorized number is fixed although the actual number available may be affected by mission, enemy, terrain, and respective equipment sets' operational readiness. See Appendix III.

# Water Point Site Selection

Water sources are described in [18]:

- a. A satisfactory water source is one of sufficient quantity to meet troop needs and of such quality that it can be approved for use or readily purified by available equipment. A water source developed for military use is called a water point.
  - b. Water sources are classified as follows:
    - (1) Surface water: streams, lakes, and rivers.
    - (2) Ground water: wells and springs.
    - (3) Sea water.

(4) Rain, snow and ice.(quote from [18])

The Division Logistics Officer [18] is responsible for providing the necessary water requirement information. With this the Division Engineer performs map reconnaissance and concurrently reviews intelligence summaries in selecting potential water point sites. On the maps are shown the road nets that provide the primary data for this research, which is distance. Hopefully, the number of potential sites exceeds the actual number that are required. The Division Engineer makes estimates as to the suitability of these sites and dispatches reconnaissance teams.

These teams then make a detailed inspection of the preliminary sites and prepare a report, DA Form 1711-R and DA Form 1712-R, on each site visited. See Appendix II. The factors to be considered are:

(i) quantity of water, (ii) quality of water, (iii) routes of communication or access and eggress, and (iv) site conditions. [18] See Appendix VII.

It should be noted that the results of this research could be applied both before and after the ground reconnaissance. A before application based on estimates would insure that only the most pre-

ferred sites were visited by the reconnaissance team. Subsequently, this same data base of distances from the map would be used to make the final selection. The reconnaissance reports would provide the actual site capacities and equipment limitations, if any, to use in the evaluation.

The present state of the art requires that a subjective evaluation be made by the Division Engineer as to which sites are to be designated and manned for water points. [18] He must rely upon his professional judgement alone, without the benefit of numerous location analysis techniques presently available to the operations research analyst. Since it is not practical to educate all division engineers as analysts, nor to provide them with large computers, nor to let their decisions be based on quantifiable data alone, the goal is to provide a prototype DSS ready for user testing. This would allow the engineer to interact with the computer in terms of data that he can relate to while the DSS acts as a translator into and back out of the world of the analyst.

## Assumptions

In order to construct a mathematical model of this problem a number of assumptions were necessary. They are intended to place the user in the correct frame of reference to obtain maximum usefulness from this prototype system. The four assumptions that had the most impact on the final design are given here with their justification. The remaining assumptions, intended primarily for clarification, are summarized in Appendix A.

(1) The resupply effort and/or cost is proportional to the total distance all customers travel in units of gallon-miles.

It is readily accepted that many other measures of resupply effort exist. Vehicle size, fuel consumption, manhour cost for the operator, intangible costs due to the nonavailability of the vehicle for other uses and capacity per trip are a few of these. A cursory examination leads one to suspect that these measures are highly correlated with total distance traveled. Not only should the dependent variable selected accurately reflect "real world" costs, it should be reasonably amenable to quantification. Gallon-miles appears to satisfy both of these criteria.

(2) All locations and supply/demand data are considered to be static, i.e., fractions of a day are not considered.

The anticipated frequency with which water points are moved was the primary consideration for choosing a static as opposed to a dynamic approach. Movement of supported units is dictated by the tactical situation and may be more or less frequent than daily. The movement of water point equipment sets may not be necessarily so costly as to justify moving them in advance of the supported units. The daily frame of reference facilitates the utilization of existing publications for estimating supply/demand, e.g., demand data is in terms of gallons per man per day. [18]

(3) All needed information or data required is readily available to the Division Engineer.

map drawn to scale, present supported unit locations with respective personnel strengths, water point reconnaissance reports, and current operations orders. The map provides the road network that is traced in on the digitizer pad. Supported unit locations are used to specify the demand points, and the strengths are required to estimate the amount of respective demand. The preferred water point locations and site capacities may be identified from the reconnaissance reports. See Appendix II. The Operations Order provides all of those site location considerations not included in this prototype, i.e., security requirements, planned offensive/defensive operations, anticipated enemy actions, etc.

(4) There is no additional fixed cost of establishing one water point site over another.

This simplifying assumption is possible due to the human interaction in the solution process. This decision, to base the cost of locating the water points solely as a function of distance from the units it supplies, was not arrived at easily. It was necessary to keep the cost criteria simple to facilitate implementation on equipment that could conceivably be placed in the division's combat engineer battalion. It should be noted that the Division Engineer is both the commander of the division's engineer battalion and a special staff officer.

There is no civilian parallel to the military situation which can be adapted to determine costs. A few of the tactical criteria are

site drainage, security, bivouac for operating personnel and future tactical operations. See Appendix VII. For the military there are no overtime costs. One site may require more preparation than another, but this is best taken into account by the user once he has assessed the desirability of locating a water point at a particular location. The truck that pulls the water trailer is a general-purpose truck not solely devoted to water resupply. It is also used to transport other types of supplies that are usually not located with or near the water point. The requirement then becomes one of minimizing the non-available time of the truck. The cost factor is then merely the distance the trucks must travel for water. The human is more capable than any mathematical model of taking into account the myriad of tactical and operational factors associated with site selection.

# Analysis of the Water Point Location Problem

The problem that this research addresses is in the category known as location-allocation. Problems of this nature involve the placement of one or more sources which will be used to satisfy, in an optimum manner, demands at various destinations. What must be determined is the location of the sources and the distribution or allocation of the commodity so that the destinations are supplied most economically.

The supply points are selected from a finite set that includes all acceptable locations. This problem is most easily visualized and subsequently solved as that of selecting source nodes in a distribution network.

The establishment of a source involves setting up a distribution center for the production of goods or in this case, gallons of water. The allocation part involves the distribution of the goods from these sources, through intermediate points such as road intersections, to the demand points. When either the source site selection or allocation of the distribution of goods is considered separately the solution is greatly simplified. However, in order to correctly analyze the complete problem, both aspects must be considered at once. The location of the supply points must be made simultaneously with the determination of the most economical goods allocation.

This problem can then be stated as the following: Given:

The supported unit locations,  $\{x_j, y_j\}$  and demands,  $\{b_j\}$ . The water point locations,  $\{x_i, y_i\}$  and capacities,  $\{q_i\}$ . Round trip distances among all points,  $\{d_{ij}\}$ .

The total number of water point equipment sets available, {r }.
Select:

The number,  $\{y_i\}$  and location,  $\{x_i,y_i\}$  of the water points. The needed production capacity of each source,  $\{q_i\}$ .

The allocation of the water from each water point to each supported unit.

# Methodology

A thorough study of the potential users' requirements, implementation equipment limitations and existing solution procedures resulted in a heuristic approach being selected. This approach will give a good, but not necessarily optimal, answer. The solution method implemented is:

- (1) Data input by user and machine: Network  $\{I,J\}$ , distances  $\{d_{i,j}\}$  and potential combat unit and water point locations.
- (2) Specification by user of supported unit demands:  $\{b_i\}$
- (3) Selection by user of the number of open sources  $\{y_i\}$  and their respective supplies  $\{q_i\}$ .
- (4) Shortest path solution by machine:  $Cost\{c_{i,j}\}$  (Only on initial iteration or upon changing water point locations.)
- (5) Transportation solution by machine: Flows  $\{x_{ij}\}$  and total cost Z.
- (6) Presentation by machine of solution quality indicators: Loading of each source  $\Sigma_{i}x_{ij}$  vs  $q_{i}$ , allocation of costs per unit of flow over water points  $\Sigma_{j}$   $x_{1j}c_{1j}/\Sigma_{i}x_{1j}$ , total distances traveled by demand points  $\Sigma_{j}$   $x_{1j}c_{1j}$  and alternative costs for each demand point.
- (7) Decision by user: Return to either (1), (2), (3) or stop.

The first step is the preparation of an initial data base. The road network in the area of concern is identified and input using the digitizer pad. All potential, but not necessarily utilized, supported unit locations and water point locations are entered as nodes on the network.

The second step is specification by the user of the estimated demand for each supported unit. For each unit a personnel strength is

entered. A demand is computed and then transformed to an integer number of trips that the supported unit will have to make in satisfying its demand per day. This integer value is obtained by rounding up.

The third step is the selection by the user of those water point locations that are to be considered and their respective supply limitations. The minimum of either the amount of water available or capacity of the equipment to purify water is determined and used as that site's supply capacity.

The fourth step is the computation of all shortest paths from each of the selected water points to all other points in the network.

The fifth step is the allocation of water supply capacity to units' requirements so that total distance traveled is minimized.

The sixth step is a sensitivity analysis of the results presented to the user in graphical format. This enables the user to readily identify which of his potential water points are not fully utilized and are therefore, candidates for elimination. Any of the supporting numerical data can be requested and displayed concurrently with the graphs. "What if" questions may be proposed and analyzed by forcing a particular supported unit to be serviced by a particular water point. This great flexibility for rapid analysis and cross checking allows the user to take into account all of those factors that cannot be accurately or practically modeled, i.e., mission, enemy, terrain and command guidance.

The seventh step involves the user making a decision as to

which sites are to be opened or closed. The user may then return to any of the first three steps and initiate a more thorough analysis. This subsequent analysis can then also be a candidate solution and modified as desired.

STATE CHANGE PARTIES

One limitation of this procedure is that an exact optimum is probably not attained, e.g., we start with all sites used and eliminate as many as the users' judgement dictates. Since experience with optimization dictates that even an exact optimum may not be acceptable to the user without some modification, this will not detract from its usefulness. Another limitation is that a human must identify the possible sites to be closed from graphs. This opportunity for error will be present in the final answer even though pattern recognition is one of the functions a human performs best and the computer worst.

# <u>Overview</u>

The introduction is intended to familiarize the reader with the basic design considerations and operations research techniques employed. Chapter II will cover what similar research has been conducted in this area. A description of the mathematics involved will also be found. Here both the location-allocation formulation and the reduced transportation formulation is presented. Chapter III provides a step-by-step example approach of the decision making procedure with relevant pictures from the screen.

Implementation of the four step solution procedure can be reviewed in Chapter IV, including a flowchart outline. In Chapter V

the results and performance of the program on a case problem are documented. See Appendix VI. This final chapter also suggests further development of this prototype DSS.

The code for programs  $\underline{\text{NTRACE}}$  and  $\underline{\text{COMPUTE}}$  may be found in Appendix IV and V respectively.

#### CHAPTER II

## MATHEMATICAL FORMULATION AND PAST WORK

# Mathematical Formulation

The mathematical formulation that comes closest to representing the Water Point Location problem is the location-allocation problem. As given by Ellwein, [16] the formulation is:

minimize 
$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij} x_{ij} + \sum_{i=1}^{m} g_{i} (\sum_{j=1}^{n} x_{ij}) + \sum_{i=1}^{m} f_{i} y_{i}$$

subject to:

The zero-one decision variables  $y_1$  indicate whether water point i is selected for use;  $y_1=0$  implies that location i is not used and  $y_1=1$  implies that it is used. Each continuous decision variable  $x_{1:1}$  represents the non-negative amount of water that point i provides

to supported unit j. The first two constraints state that the demand at each supported unit must be satisfied and that the availability of water at a point must not be exceeded, respectively. It can be seen that the output from point i,  $\Sigma_j$   $\mathbf{x}_{ij}$ , can be positive only if a source is established there, i.e., only if  $\mathbf{y}_i$ =1. The third inequality represents a set of p system configuration constraints where  $S_t$  is a subset of the m water point locations and  $\mathbf{r}_t \leq \mathbf{m}$ . This is the same as saying that we can not establish more water points than we have water purification equipment sets available.

The objective function is to minimize a function representing both the source and distribution variable costs plus the fixed cost components. All cost coefficients or distances traveled must be greater than zero. The problem then is that of determining the optimal trade-off between a large number of water points with low total distance and a small number of water points with high total distance traveled. This problem formulation is more general than that implemented in this thesis.

The fixed cost represented by  $f_i$  for each site will be assumed to be the same for all sites; furthermore, the <u>user</u> chooses the number of water points so that fixed costs may be assumed to be zero. This results in the objective function being expressed as:

minimize 
$$Z = \sum_{i=1}^{m} \sum_{j=1}^{n} d_{ij}^{*}x_{ij}$$

where  $x_{ij}$  is the integer number of trips needed to satisfy the demand for a supported unit at j traveling over the shortest route,  $d_{ij}$ , to

water point i.

The third constraint can be deleted since the user specifies those sites to be considered as locations for water points. Subsequent to the analysis he then manually reduces this set again for reevaluation of the entire problem. The demand for the supported units in terms of gallons per man per day may be changed to an integer number of trips required. This is accomplished by dividing by the per trip capacity of the transport or in this case a 400 gallon trailer pulled by a single truck. The resulting answer is rounded up to the nearest integer since realistically the trailer would always be filled on each trip, i.e., one would not pull a 400 gallon trailer and only put 50 gallons in it even if only 50 gallons were required. The capacity of each water point site to provide water can likewise be converted to an integer number of trips available, except that the result is rounded down to insure that supply is not exceeded.

With this, the formulation of P becomes:

m n+1
minimize 
$$Z = \sum_{i=1}^{\infty} \sum_{j=1}^{\infty} d_{ij} x_{ij}$$

subject to:

$$\frac{m}{j=1} \times ij = \begin{bmatrix} q_1 \\ 400 \end{bmatrix} \quad i=1,2,\cdots,m \quad \text{"demand is satisfied"}$$

$$\frac{m}{j=1} \times ij = \begin{bmatrix} b_j \\ 400 \end{bmatrix} \quad j=1,2,\cdots,n \quad \text{"supply is not exceeded"}$$

# $x_{ij} \ge 0$ and integer

A dummy demand point is created at location n+1 to absorb all excess supply. This is a necessary condition for the transportation algorithm. The cost of providing supply to the dummy demand point from any source is then zero. In the display of the results the amount of water provided to the dummy demand point is subtracted from the amount produced.

# Past Work

A review of published articles has revealed an abundance of reported research on facility location-allocation with capacity constraints. [16,22,23,24,25,27,46] One of the first exact algorithms to deal with the uncapacitated case is that of Efroymson and Ray [14] and Spielberg. [48] Recent research, which includes exact algorithms and computational experience specifically for the capacitated plant problem, has been done by Rardin [44,45,46] and Geoffrion. [23,24,25] An excellent survey of the current state of the art for exact solutions is presented by McGinnis: [38]

Spielberg was able to solve randomly generated uncapacitated problems with 20 to 100 sites in 1 to 75 minutes on an IBM 360/40[47] and 52-100 sites in 2 to 167 minutes on an IBM 360/50.[48] Rardin[46] solved some randomly generated problems on a Univac 1108 with results summarized in table 3 · · · Geoffrion and Graves[24] considered an even more general problem which had two stages of delivery, no customer serviced by more than one supply point, and deliveries to customer identified by point of orgin. The solution procedure they describe is a variant of Benders partitioning algorithm, and was capable of solving problems with up to 30 sites in 17 to 191 seconds on an IBM 360/91. (quote from [38])

All of these presently accepted methods of obtaining global

optimal answers to the location-allocation class of problems with capacity constraints utilize heavily the techniques of integer programming. The codes developed for their implementation require large, high speed computers to produce satisfactory results. Many advances in the rapid solution of these problems have been accomplished by Rardin [45,46] and Geoffrion. [25]

A heuristic procedure by Kuehn and Hamburger [36] represents the first work on solving the plant location problem. Subsequent work by Manne [37] and Feldman, Lehrer, and Ray [17] resulted in approximate algorithms. A major reason for the development of these heuristics was the reduction of computer time necessary to find reasonable solutions. Trade-offs arise in this procedure because of the lack of a guarantee of reaching an optimal solution due to the heuristics, and because of the approximations that are made to the cost equations. The heuristics are used to assign customers to sources and to open or close sources, such that the number of alternatives evaluated is quite small. The result of applying these heuristics is that one can quickly determine a good set of sources in minimum computer time.

Atkins and Shiver [2] indicate potential savings of from 5 to 15% over good manual solutions when using these techniques. There are simply too many combinations and too much detail to rely on manual techniques for solving this problem. The current state of the art provides a very acceptable alternative. (quote from [35])

The identified difficulty of optimally solving a realistic resupply point location problem and having its solution readily available to the Division Engineer resulted in a heuristic procedure being selected for implementation. (See Chapter I, Methodology) This

is justified by the simultaneously complex and repetitive nature of this problem when placed in the tactical operational environment. The search for an efficient and effective heuristic procedure with the flexibility to handle nearly any situation involved the field of interactive graphics. With the rapid advances in computer technology and its subsequent implementation, interactive graphics solution of location problems has flourished. [6.7.33]

This is primarily due to the mathematical difficulties encountered in obtaining exact answers, i.e., most location problems are considered to be NP-complete which is a class of problems not solvable in all cases. For those that are solvable the effort required to enumerate all of the possible solutions may require large consumption of computer processing time. Interactive graphics allows the human to inject his pattern recognition abilities into the solution process. He thereby eliminates many of the possible, but not optimal solutions from the set of those to be enumerated by the computer.

A desire to implement the heuristic procedure on the state of the art Chromatics color graphics terminal without use of a host computer resulted in a search for efficient algorithms. The use of minicomputers in this area has been facilitated by the work of Glover and Klingman. [26,27,28] They have had significant success at developing highly efficient computer codes for many of the existing algorithms. The desirability of utilizing the Chromatics in this manner is clearly expressed by Elam:

The availability of efficient mathematical programming software on minicomputer systems could greatly increase the use of

operations research techniques in industry and government simply by placing a decision-making capability at the finger tips of managers. In fact, since minicomputers are relatively inexpensive, it is also possible to dedicate a minicomputer to solving a specific decision problem and thus create an environment which is conductive to an efficient man/machine decision making system. This could be accomplished by designing the operating system of the minicomputer to improve the human engineering aspects of problem solving that is, to minimize the difficulties of entering, modifying and verifying problem data, passing the problem data to the solution procedure, interpreting the output, and so forth. (quote from [15])

Additional research on this problem has recently been accomplished by Glover [28] and Hudson and Flake. [33]

Three solution procedures for solving the water point locationallocation problem were considered, primal network flow, the out-ofkilter algorithm and the all integer transportation algorithm. The
first two have the advantage of being one step procedures that could
be applied directly to the problem. Their primary disadvantage is
the need to re-solve the entire problem whenever changes are made to
the supply or demands.

The choice of the transportation algorithm required that a two step procedure be used. First, an all possible shortest route problem is solved for each water point in the initial candidate set. The shortest distance values are then used to form a cost matrix to be used by the transportation algorithm. This method has the advantages that: (1) The interactive solution approach could be implemented so that one shortest-route problem is solved. This is followed by a sequence of transportation problems all using the existing shortest route values. (2) A large number of "what if" or sensitivity analysis questions can be treated by re-solving the transportation code without

re-solving the shortest-route problem. (3) The best of the existing heuristic procedures for choosing site locations could be added by utilizing the output of the transportation algorithm.

These approaches are generally accepted to be variations on those strategies published by Keuhn and Hamburger, [36] Feldman, Lehrer and Ray, [17] and Maranzana. [31] Khumawala and Whybark [35] have an excellent summary of the first two.

#### CHAPTER III

#### THE DECISION MAKING PROCEDURE

The existing decision making process for water point location can be summarized as follows:

- Phase 1 Establish a requirement for water points:
  - Step 1 Collect supported unit data.
  - Step 2 Calculate demand quantities.
- Phase 2 Perform water point site selection:
  - Step 1 Perform a map reconnaissance.
  - Step 2 Dispatch reconnaissance teams to potential sites.
  - Step 3 Make a subjective evaluation of results.
  - Step 4 Select the actual sites.
- Phase 3 Establish water points and inform supported units. [18]
  - This DSS would modify this as follows:
- Phase 1 Establish a requirement for water points:
  - Step 1 Collect supported unit data.
- Phase 2 Perform water point site selection:
  - Step 1 Perform a map reconnaissance.
  - Step 2 Input road network with digitizer. (In future implementation, obtain a disk with predigitized map.)
  - Step 3 Input unit locations and feasible sites with light pen. (Alternative means of entering data could be provided.)
  - Step 4 DSS computes supply and demand.
  - Step 5 Interactively evaluate feasible water point sites.
  - Step 6 Dispatch reconnaissance teams to potential locations.
  - Step 7 Interactively select actual sites.
- Phase 3 Establish water points and inform supported units.

Phase 4 - Reoptimize original data when the tactical situation changes.

In this interactive DSS there is no exact or abrupt end of the selection process. Analysis of the graphical results can be repeated or revised as desired, using the DSS as a vehicle for storing, viewing, editing and analyzing site locations, entering judgements and opinions, and presenting the solution with supporting data.

There are several avenues for arriving at a decision using the DSS. Features included in the DSS are color computer graphics, giving the user a pictorial view of the map area of interest; techniques for changing the capacities of the potential water points and demands for the respective supported units; use of network analysis to select routes; siting analysis to compare the potential locations; and graphing routines to evaluate the results. The attempt is to provide a flexible system that will fulfill the needs of both novice and experienced users.

The structure is this: The user chooses the water points; with this choice the problem is reduced to a network flow problem. This is solved as a combination of several shortest-path problems and a transportation problem since all the shortest-path problems can be solved in advance. The result is a solution that is optimal for the additional constraint of the water point locations chosen. Pricing information is then given to the user, who can then alter the additional constraints, i.e., change the chosen set of water points; the process is repeated until the user is satisfied.

Possible paths through the subsystems of the DSS may be

depicted as follows:

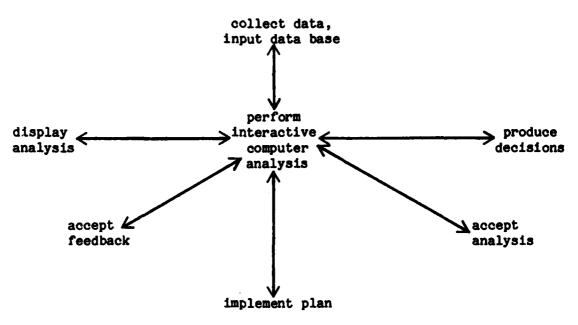


Figure 1. Users' Interaction With the DSS

After calculations have been performed for a given set of open water points, the DSS provides three methods of investigating the sites under consideration: (i) graphical representation of the distances supported units must travel per unit flow and the actual production flow of each water point, (ii) numerical data to investigate the graphical representation, and (iii) sensitivity analysis by forcing a supported unit to be served by a particular water point and re-solving the transportation problem.

There are four different graphs that can be requested. All are accessed by selecting the DISPLAY ANALYSIS menu item with the light pen:



The following prompt will then appear in the lower right corner of the screen:

YOU HAVE A CHOICE OF 4 GRAPHS AND/OR NUMERICAL DATA.

#1 = ''GALLONS SUPPLIED VS SITE #.''

#2 = ''MOST EFFICIENT SUPPLY PT.''

#3 = ''MOST COSTLY SUPPORTED UNIT.''

#4 = ''DISTANCE TRAVELED VS SOURCE.''

#5 = ''INDIVIDUAL ANALYSIS.''

#6 = "'RESUME LIGHT PEN CONTROL."

## ENTER NUMBER SELECTED?

# Figure 2. Display Analysis Menu

All of the DISPLAY ANALYSIS subroutines are controlled using the keyboard as the input device.

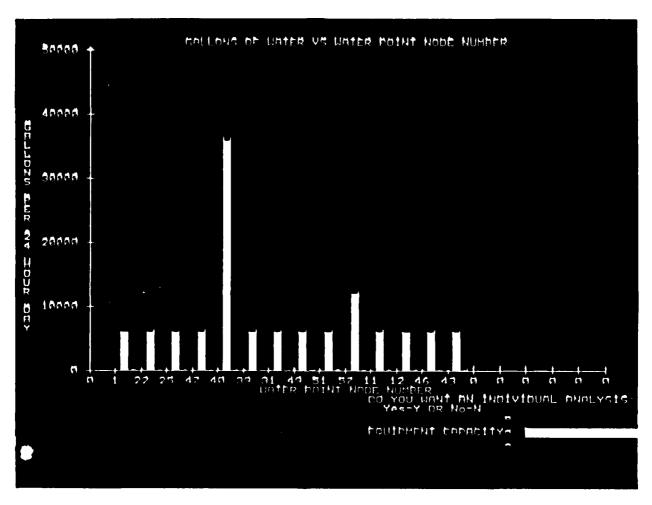


Figure 3. Gallons Supplied vs Site #

The first graph, #1, is the actual demand upon respective water points in comparison to its potential capacity if more equipment sets were allocated. Three bars are plotted for each water point. The green bar is the capacity of the potential water site's source to provide water, e.g., wells, rivers, etc. The yellow bar is the capacity of the water point's purification equipment, given design limitations and the number of equipment sets allocated to that site. The red bar depicts the consumption of water from that water point site by the supported units. This graph is intended to identify any sites not being utilized and any whose production capacity could be increased by the addition of more equipment sets.

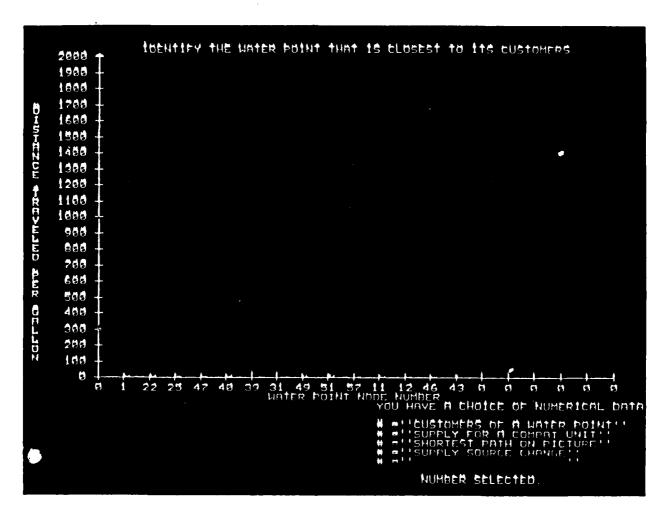


Figure 4. Most Efficient Supply Point

The second graph, #2, is the ratio of the total distance traveled by the customers of a water point to the number of gallons of water that point produces. Distance for each water point is summed over only those supported units drawing from that water point. This graph is intended to identify the most efficient and the most uneconomical water points, i.e., the smaller the ratio the closer the supported units, and vice versa.

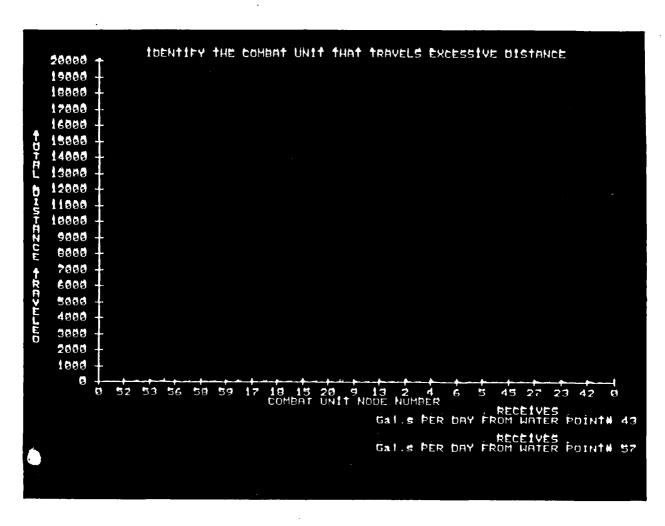


Figure 5. Most Costly Supported Unit

The third graph, #3, has two bars plotted for each supported unit. The red bar reflects the total distance traveled by each supported unit in obtaining its required quantity of water. The green bar is a ratio of that same total distance to that supported unit's required quantity of water. This graph is intended to identify the supported units that have to travel the farthest distances.

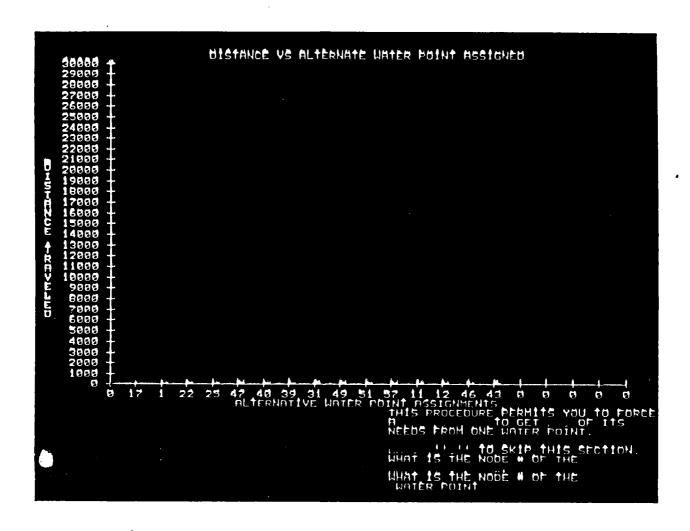


Figure 6. Distance Traveled vs Source

The fourth graph, #4, is actually a series of different graphs that can be requested, one for each supported unit. The dark blue represents the distance traveled by that supported unit if no changes are made. The magenta depicts the increased or decreased distance that would be traveled by that unit, if it received all of its supply from any of the other water points. This graph is intended to select that water point that would best serve a particular unit if all other units are ignored.

The individual analysis, #5, provides several options. It may be selected concurrently with any graph to verify or explain any particular result observed. These same data provide the final solution once the analysis is completed and the actual locations selected.

The following prompt will appear in the lower right corner of the screen:

YOU HAVE A CHOICE OF NUMERICAL DATA.

#1 = ''CUSTOMERS OF A WATER POINT.''

#2 = ''SUPPLY FOR A SUPPORTED UNIT.''

#3 = ''SHORTEST-PATH ON PICTURE.''

#4 = ''SUPPLY SOURCE CHANGE.''

#5 = ''RETURN TO GRAPH MENU.''

#### ENTER NUMBER SELECTED?

Figure 7. Individual Analysis Menu

The shortest route between any two nodes in the network may be plotted by selecting Individual Analysis item #3, Shortest Route.

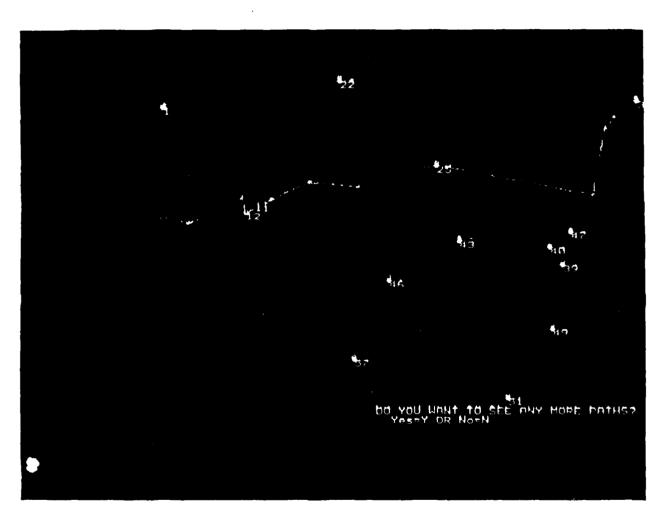


Figure 8. Shortest Route

In addition, the individual analysis routine #4, allows an individual supported unit to be selected to receive all of its supply from a particular water point. All subsequent graphs would then reflect this change. (To return to original conditions it is necessary to recompute the flow.)

The following prompt will appear in the lower right portion of the screen if the RESTART menu point is selected with the light pen:

#1 = ''COMPLETE RESTART''

#2 = ''MAJOR RESTART''

#3 = ''MINOR RESTART''

#4 = ''RETURN TO LIGHT PEN CONTROL.''

## ENTER YOUR SELECTION?

# Figure 9. Restart Menu

The RESTART light pen menu item provides three capabilities. The first item, #1, executes a complete restart. A complete restart requires the user to trace in a new road network. The old network is not destroyed, it is only erased from the screen and may be recalled by initiating the <a href="NTRACE">NTRACE</a> program. <a href="ALWAYS">ALWAYS</a> place a disk containing only system files and programs <a href="NTRACE">NTRACE</a> and <a href="COMPUTE">COMPUTE</a> in disk drive #1 before tracing in a new road network. (The disk does not have sufficient memory space to store more than one road network picture at a time.)

A minor restart, item #2, erases the current supply and demand capacity values and permits the changing of the constant values. A major restart allows all of the data existing under one name to be assigned a new problem name and copied to a second disk. (The

original data is not destroyed. Only a duplicate is made under the new file name.)

After analysis for a given set of open water points, the user may return to the data input portion to make changes in the number and capacity of water points. The flow must then be recomputed (COMPUTE FLOW) and another analysis of the results performed.

An attempt was made during the writing of the code to make the procedure as "forgiving" as possible. The combination of video and message prompts should lead anyone with a rudimentary knowledge as to what is important for the location of military water points through the solution procedure.

At key points the operator is required to respond to YES or NO prompts. This requires a keyboard entry followed by pressing the RETURN key. If RETURN only is pressed in response it will be accepted as a NO response to the prompt. Only the letter Y need be entered to imply a YES response.

After each graph is drawn the user is prompted for a numerical data request. This is particularly useful in explaining or clarifying graphical results that may have impact on the location selection.

The entire program was written in such a manner that a carriage return or null response to any of the DISPLAY ANALYSIS input prompts will cause that subroutine to be skipped. This also enables any user who becomes "lost" in his analysis of the data to always return to light pen control by entering multiple carriage returns. The prompt, LIGHT PEN ACTIVATED, will appear when the user has left the DISPLAY ANALYSIS package of subroutines.

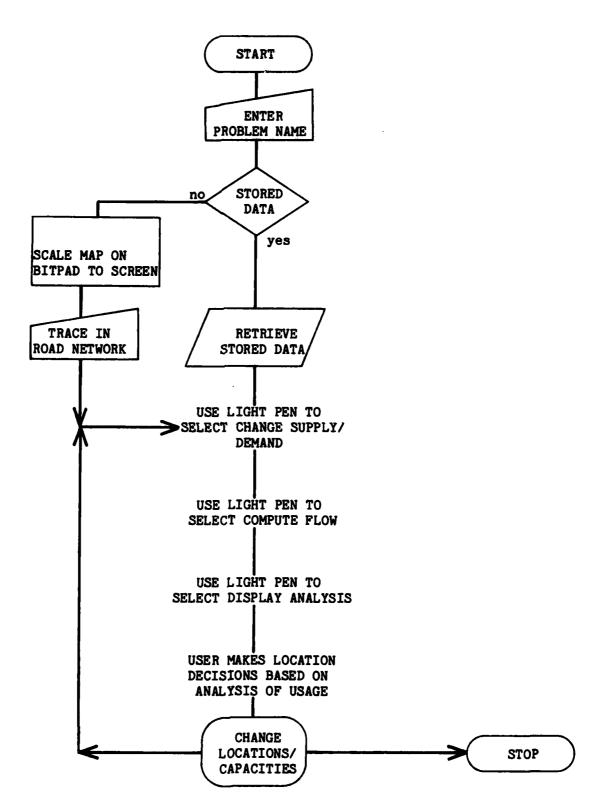


Figure 10. Flowchart of User Actions

#### CHAPTER IV

### IMPLEMENTATION AND DOCUMENTATION

# Instrumentation and Equipment

The primary item of equipment utilized in this research is the Chromatics color graphics minicomputer. [43] It is a complete, self-contained, high-resolution (512 X 512 dot matrix) color graphics terminal with an integral Z-80 microprocessor, attached floppy disk drives and 64K bytes of random access memory. Its high resolution screen provides a choice of from one to eight colors and automatically generates geometric figures.

In addition, the terminal is equipped with a light pen. This is a device that can detect light on the screen and feed a signal back to the terminal. This signal is used to determine where the pen is located in relation to the screen. This is the primary device for controlling program execution.

A digitizer pad is utilized to input the visual representation of the road network. [5] This accessory to the terminal converts graphic information into digital form suitable for use by the Z-80 microprocessor. It is utilized by positioning crosshairs or touching a stylus to any position on a map that is affixed to the pad's surface. The x,y coordinates of that position are transformed into their digital equivalents and transmitted to the terminal for processing.

## **Implementation**

All programming was accomplished using Chromatics Basic Language. [8,9,13,43] The primary blocks are: (i) map data input, (ii) menu selection control, (iii) general purpose data input, (iv) data manipulation, (v) computations execution, and (vi) display of the results.

Due to the size of the program, approximately 1000 lines, the program was divided into two separate programs. Program NTRACE controls data entry and manipulation and calls the COMPUTE program.

NTRACE provides light pen selection of menu items: ADD NODE/ARC, STOP OR SAVE DATA, CHANGE SUPPLY/DEMAND, and RESTART. A selection of menu items COMPUTE FLOW or DISPLAY ANALYSIS while under the control of program NTRACE, results in all accumulated data being saved on disk and program COMPUTE being retrieved from the disk and execution initiated.

Program <u>COMPUTE</u> performs all calculations and controls the display of the results. <u>COMPUTE</u> provides light pen selection of menu items: STOP, COMPUTE FLOW and DISPLAY ANALYSIS. While under the control of program <u>COMPUTE</u>, a light pen selection of menu items ADD NODE/ARC, CHANGE SUPPLY/DEMAND, and RESTART results in chaining back to program <u>NTRACE</u> for subsequent execution. The results of the calculations are not saved on the disk; COMPUTE FLOW must always be executed prior to DISPLAY ANALYSIS, and is automatically chosen if the user elects to ask for analysis when no results of flow computation are available.

Throughout both programs the intent was to make them as foolproof as this researcher's ingenuity would permit. It is intended to be possible for one to operate the entire program with no background as to what the correct solution procedure is.

# Data Storage and Manipulation

The primary array is one for general purpose storage. This array, NN, is the only array that is not dynamically dimensioned based on the maximum number of nodes in the problem, variable name MA. NN is utilized to store the limiting parameters of the problem and its values are used to dimension subsequent arrays. Another use of NN is in testing to see if the operator is performing solution steps that are improper. The program checks for the existence in NN of various stored values needed to perform requested procedures; either execution is allowed to proceed, control is shunted to a prerequisite procedure, or the user is prompted as to what can be done.

The IF statements to check for variables having values greater than zero are of the form IF (variable) THEN (line number). Any value other than zero results in the appropriate branching of the program in order for execution to proceed. A value of zero is interpreted by the machine as a signal that data needed for continued execution does not exist.

The largest memory requirement comes from the storage of the data input from the map using the BITPAD digitizer. This data is stored in three different arrays. The main one, D(I,J), stores the distance from any node I to any node J that are joined by an unin-

terrupted arc. This value is stored as a two way arc so it is only necessary to trace each road section once. Array D(I,J) is dimensioned to be the same size as the number of nodes in the problem. That is for the maximum of 60 nodes, D(I,J) becomes a 60x60 matrix. Since 60x60 is the largest array that the Chromatics can handle, this is the constraint on the maximum number of nodes. (Use of a linked list can greatly increase this maximum in future implementations.)

The other two arrays are NX and NY. These store, respectively, the screen's X and Y coordinate of each node. They are by necessity dimensioned to be the same as the number of nodes, variable name MA. Arrays NX and NY are used to plot the change of the node colors on the screen.

The search for an efficient shortest path algorithm resulted in the next set of arrays. A shortest path algorithm by Pape [15,41] required input to be in forward star format. This utilizes three arrays, NS, NT and AL. They are generated from the D(I,J) matrix and stored for use by program COMPUTE. In simple terms, they compress all of the zeros representing nonexistent arcs out of the D(I,J) matrix. This greatly reduces the amount of memory required and also permits rapid access to the next arc when finding shortest distance paths. A relatively sparse network is assumed, with the average number of arcs per node being less than five. This only affects the dimensioning of the linklist arrays, NT and AL.

The input of data for the respective water point nodes and combat units resulted in four arrays. Two of them are pointers to the nodes that are water points or sources, array SR, and nodes that are supported units or sinks, array SK. Array Q stores the capacity of each water site designated and the demand for each supported unit. It is dimensioned to be the maximum number of nodes and therefore has the capability to store a capacity for every node in the network. This prohibits the designation of a node as both a demand location and a supply location. Array IS stores the capacity of each water point based on the minimum of either the equipment or that site's source of water.

This completes the data base needed for all calculations. All subsequent arrays and matrices are dimensioned based on the number of water points and the number of supported units. These values are stored in variable names NN(7) and NN(8) respectively.

The transportation algorithm requires a cost matrix, IC(S,T), that contains the shortest round trip distance from each water point to each supported unit. A dummy supported unit is created to consume the excess supply at the last column position. The results from the transportation algorithm are stored in a compacted tree structure. [39]

The plotting routine utilizes three arrays, X,Y and NP. X and Y store the values to be scaled for the respective coordinates. NP stores the numbers to be plotted as node numbers on the X axis.

Menu Operation

The menu selection routine uses two different identifiers to make a selection of the action to be initiated. They are the value of variable name HT and the location of the light pen hit on the screen.

The value of HT is alternately assigned integer values to be used in the ON HT GOTO · · · statement. This insures that if a hit is made on the screen in the wrong place for the section being utilized, it will be ignored. In addition it branches the interrupt back to the correct line in the program for continued execution.

If HT=1, then the menu points are allowed to initiate new action. Otherwise, hits in the menu section will be ignored.

ADD
HT=5 for network data input
HT=6 for termination of
digitizing.

STOP OR
HT=1 menu hit is allowed
SAVE DATA

CHANGE

HT=2 for water point data input

HT=3 for supported unit data input

HT=4 for change in problem size

SUPPLY/DEMAND

HT=1 menu hit is allowed
"Light Pen Inactivated"
(Until Completion)

DISPLAY

HT=1 menu hit is allowed

"Light Pen Inactivated"

(Until Completion)

### Add Node/Arc

The ADD NODE/ARC subroutine will be automatically entered each time a new road network is being traced in. When this subroutine is being executed the message, "DIGITIZER ACTIVATED," will appear in the lower right portion of the screen. Once this message appears the user must insure that there is a disk with sufficient space available to store a PIC file, 300 sectors, mounted on the drive being utilized. Otherwise the system will try to store data where no space exists.

In addition to entering a new road network, this subroutine may be chosen when the user wishes to make modifications to the existing network. By selecting ADD NODE/ARC with the light pen after a network has been entered and saved on disk, the user can then specify the distance of any arc by over-writing the stored data, e.g., set an arc to zero if a road was destroyed. Caution must be exercised, in that all arcs are stored as two-way distances. Therefore, to completely cancel out an arc from the network the distance from the start to end point and vice versa must both be set to zero. Also, if only a one-way distance is set to zero the program will still allow travel in the opposite direction when calculating shortest paths, so overall effort is no longer minimized. If the user anticipates ever restoring the original distances they must be recorded and reentered.

#### Compute Flow

Three computational actions take place during execution of COMPUTE FLOW.

First is the computation of the shortest paths from each of the

water points to each supported unit respectively. These are first stored in a matrix and then upon termination of the program, are stored on disk. This shortens the time needed for the program to perform subsequent analysis of the saved data. Approximately 30 seconds per water point node for a 60 node problem is required for shortest-path computation.

Second is the search through the potential site capacities and all of the unit demands for an initial solution. This is necessary in order for any optimization to take place. Approximately 30 seconds is required for the initial solution.

Third is the application of the transportation algorithm to this initial solution. The transportation algorithm repeatedly modifies this initial solution in such a manner that the total distance traveled by all of the supported units in getting their water is reduced at each iteration. Approximately 10 seconds is required per interation.

#### Display of the Results

This section contains several subroutines that act as data manipulators. They utilize as input the data from the COMPUTE FLOW calculations and call upon a graphing routine to display the results.

This is an entire package of subroutines that allow access to other packages of subroutines. It is as flexible and useful as the user's imagination will allow. See Chapter III for a more detailed description of its use.

# Restart

The RESTART section is a general purpose function that should have intuitive appeal to the user. To a user totally familiar with the program and the system commands of the Chromatics it is an unnecessary routine. Once a user has decided to change the number or capacity of either the supported units or water points a MINOR RESTART may be requested. This transfers execution back to program NTRACE for the change of the problem's initial constants.

The MAJOR RESTART routine allows the user to start a new problem with a new name using a data base previously input under a different name. This would be useful if the user wishes to retain all of the data associated with a particular set of locations. Note: Any changes to one particular problem require at most a MINOR RESTART.

A listing of the actual code with appropriate comments may be found in Appendix VI AND VII. The code is internally documented with comment statements.

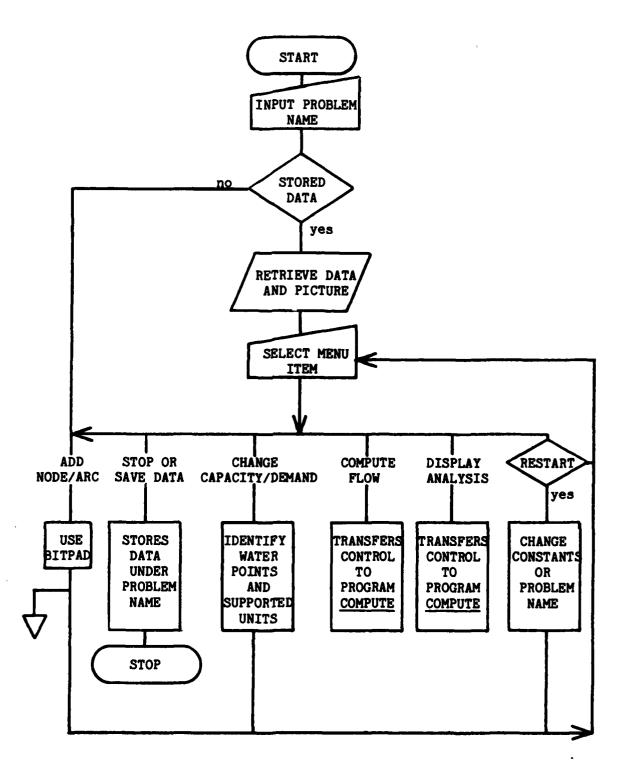


Figure 11. Flowchart of Program NTRACE

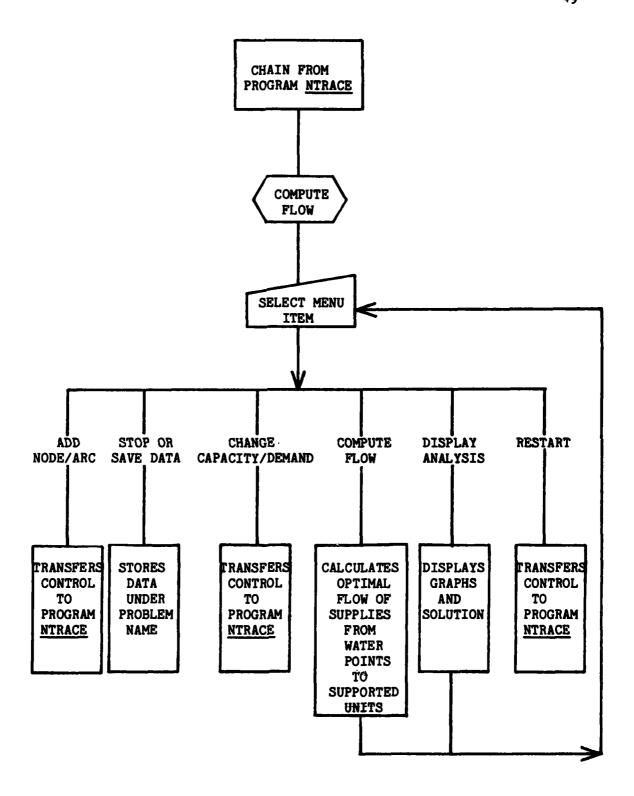


Figure 12. Flowchart of Program COMPUTE

### Procedure

This Decision Support System was designed to be interactive. That is, it requests data from the user using sentence structure together with visual prompts. These assist the user in entering the needed data at the proper time. In most instances an erroneous entry will be ignored and a new request for the same data initiated. In other cases the results of the entry will be displayed visually. It is up to the user then to identify that an erroneous entry has been made and correct it by reentering the correct data. Only the most recent entry will be remembered by the system.

The program will not function unless a data base is first created and stored for subsequent processing. The required data base is input to the terminal using the digitizer pad. First the area of operations is determined and a map sheet of appropriate scale selected. The entire area must be no larger than the ten inch by ten inch tracing area on the digitizer pad. If a map of sufficiently large scale is not readily available, then a smaller map may be adapted by employing a reducing reproduction machine.

The program will prompt the user as to the correct method of scaling the area selected so that it will be proportionately displayed on the screen.

When the scaling is complete, the road, rail or any similar set of movement routes may be traced. Due to the extreme difficulty in having a computer recognize the intersection of roads, all portions of the road traced must start and end at a node. Correspondingly, the user must first designate all supply points and demand points as nodes. A node is just another name for a start point or an end point.

Since it is desirable that all possible paths or routes of travel between the supply points and demand points be considered in the solution, each potential route must be traced. It can be readily visualized that for even small problems the potential number of routes from each supply node to every demand node can result in an unmanageable number of segments.

The number of paths that must be traced to connect each node to all possible routes is greatly reduced by designating road intersections as nodes. This allows the computer to treat that intersection as a switching point so that supplies can flow in and out of it in any direction.

The four button cursor is used to designate the nodes and trace the adjoining roads. The BLUE button designates nodes and the GREEN button draws the arcs. The GREEN button must be depressed continuously as long as a road is being traced. As soon as it is released the terminal searches for the closest node. When it does not find one within 25 dots of a previously designated node it will establish one.

A road that is traced erroneously may be simply retraced. Only the most recent input is retained. Caution must be exercised in the designation of nodes. It is not possible to delete a node once it has been entered without restarting the entire digitizing procedure. Approximately 30 minutes is required to accurately digitize a 60 node

network containing 200 arcs. This procedure is recognized as being awkward. See Chapter V, Recommendations, for suggested improvements.

Once all nodes and arcs have been entered the picture and data entered will be saved before allowing execution to proceed. This precludes having to digitize the map data a second time if time does not permit a complete analysis at once. Once the initial data has been saved, the program may be stopped and restarted without loss of continuity by selecting STOP with the light pen. Note: During the execution of the CHANGE SUPPLY/DEMAND, COMPUTE FLOW and DISPLAY ANALYSIS the light pen is turned off. All ongoing calculations must be terminated before it is reactivated.

To resume program execution once the data has been saved, it is only necessary to mount the storage disk on DRIVE # 1. Then type in DOS"LOAD NTRACE" which, after execution by the Chromatics, will result in OK appearing on the screen. Now type RUN, followed by a carriage return, and follow the given instructions or answer the prompts.

Once the network data has been entered, the supply and demand nodes or water points and supported unit locations, respectively, must be designated. This is accomplished by selecting the CHANGE SUPPLY/DEMAND menu point. The prompts that appear will guide one through this procedure. All possible water points and all possible supported unit locations must be designated at this time if they have capacities greater than zero. A failure to provide sufficient supply to satisfy all demand will initiate a prompt to start over. Note:

When making changes in the capacities alone of a previously designated set of supply/demand points, a negative entry is required for termination.

After the supply and demand nodes have been designated, the COMPUTE FLOW menu item may be calculated. The results of these calculations are needed before the DISPLAY ANALYSIS routine can be entered. This is accomplished by selecting COMPUTE FLOW with the light pen. While executing computations the light pen is inactive to prevent interruption of the successive calculations. If the shortest-paths have not been calculated for the present data set, a prompt will appear informing the user that this is being done. This is followed by the initialization of the transportation algorithm and its subsequent optimization.

At this point the user is ready to conduct the analysis of the potential sites selected for consideration. See CHAPTER III for details.

#### CHAPTER V

# EXPERIMENTAL RESULTS, CONCLUSIONS AND RECOMMENDATIONS

# Experimental Results

The example water point location problem that was implemented was provided by the U.S. Army Engineer School, Ft. Belvoir, Va. This hypothetical situation is used by the Engineer School to instruct company grade officer students during the Operation Windup phase of instruction in the Engineer Officer Advanced Course.[1]

The map used for input is the same as that referenced in the operations order, AJO, 1:250,000, ARIZONA, Sheet NI 12-10. The roads traced were the secondary and primary road network in the area of concern. All roads are two-way.

Army TM 5-700 was used to provide all data pertaining to Water Point equipment and location criteria. [18] In addition, it furnished the demand data in terms of gallons per man per day. Due to the Arizona location, the climate was taken to be desert environment, requiring five gallons per man per day.

Personnel strengths of the units were computed based on the authorization given in FM 101-10-1. [49] The estimated demand for one gallon per day for each vehicle was included by rounding up the needed quanity of water for the men to the next largest trailer load.

The solution procedure of the Operation Windup case problem proceeded as follows:

Since the entire map sheet could not be digitized on the BITPAD digitizer, [5] a hypothetical area of operations was chosen. This chosen area was then reduced on a copy machine so that its road network could be contained in a  $10^{\circ}$  x  $10^{\circ}$  area.

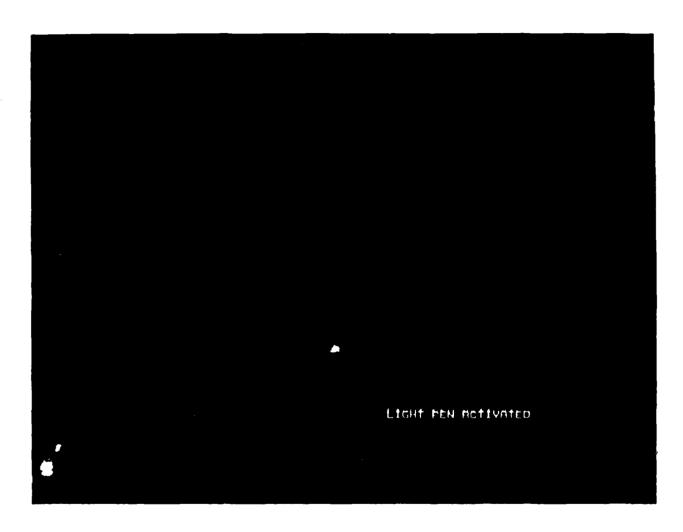


Figure 13. Digitized Road Network

After digitizing the network and before designation of the supported unit locations and potential water point sites the screen will appear similar to this.

The maneuver units and respective headquarters elements listed in the operations order were then deployed to field locations that would simulate the military situation. This resulted in 15 battalion units size combat and three brigade headquarters elements. Headquarters units are located at node numbers 5, 18, 42 and 53. Mechanized Infantry battalions are located at node numbers 4, 13, 17, 23, 45, 52, 58 and 59. Armour battalions are located at node numbers 2, 6, 9, 15, 27 and 56. The demand for the Cavalry was arbitrarily placed at node 20. Other combat service support units listed in the operations order were assumed to be part of the divisions rear element which would be a separate problem.

The units were all assumed to be at full strength. This resulted in the Mechanized Infantry and Armour battalions having respective strengths of 880 and 548 personnel and the Cavalry, 875 personnel. The brigade headquarters elements were given a strength of 372 to simulate the inclusion of elements of the direct support Combat Engineers, Field Artillery and Combat Service Support personnel together with authorized headquarters personnel. [49]

Fourteen wells were identified based on map symbols. They are located at node numbers 1, 11, 12, 22, 25, 31, 39, 40, 43, 46, 47, 49, 51 and 59. As per the special situation each well was taken to have two different capacities. With the exception of the Papago well, node

#59, each could produce at either 100 gallons-per-hour (GPH) continuously or at 500 GPH for 10-12 hours. The Papago well could sustain a continuous rate of 300 GPH or produce 1,000 GPH for 10-12 hours. All wells must set for 12 hours before pumping could resume if the maximum rate were pumped. The city of AJO water supply system could provide the division with 12,000 GPH.[1]

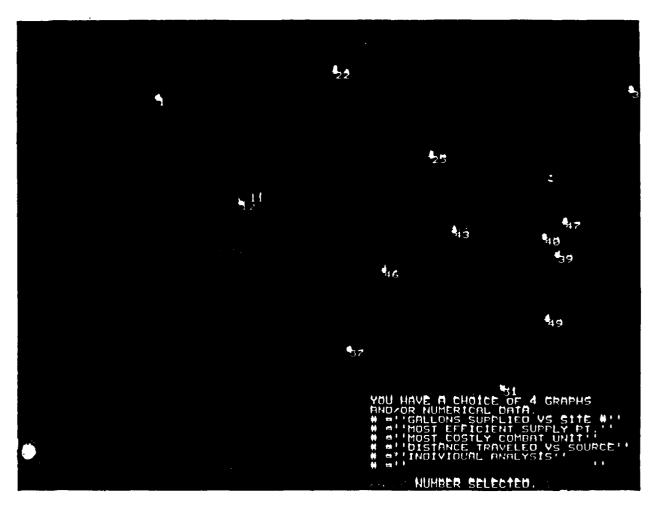


Figure 14. Digitized Network with Supply/Demand Nodes Designated

All other nodes represent road intersections or transshipment points. These were added to decrease the number of separate arcs that must be traced in order to represent all possible paths in the network.

Initially, all potential water point sites were assumed to be open or available for use at their continuous rate of production. This results in demand exceeding supply by 68 trailer loads of 400 gallons each. All water points were then increased to their maximum respective capacities. A value to enter for each water point was determined by multiplying the maximum rate of production times the average duration of 11 hours and then dividing by 24 hours. This gave a gallons per 24 hour day rate of 229 for all but the Papago well which had a new rate of 458 GPH.

To demonstrate the inclusion of nonstandard situations into the DSS the capacity of the water point at location #40 was arbitrarily increased to 2000 GPH. This is intended to simulate drawing on the city of AJO's water supply capacity.

After the calculation of the flow was complete the results were analyzed. Graph #1, Gallons Supplied VS Site #, showed that water sites #31 and 39 were not utilized and therefore should not be opened. See Figure 2, Chapter III, page 25. Additionally, water sites #1, 40 and 43 were operating at full capacity with sites #12, 49, 51 and 53 nearly at full capacity.

Graph #2, Most Efficient Supply Point, showed that water sites #1 and 46 are particularly desirable locations. See Figure 3,

Chapter III, page 26. This is because they are both close to their customers and operating at nearly full capacity. Water site #43 is a candidate for deletion if sites closer to its customers can be found.

Graph #3, Most Costly Supported Unit, showed that of all the supported units, the one at location #17 had to travel further than anyone else to satisfy its demand. See Figure 4, Chapter III, page 27. A request for numerical data and/or #5, Individual Analysis and subsequently item #2, Supply for a Supported Unit, gave its source of supply. There were 800 gallons from site #43, 3600 gallons from site #57 and 400 gallons from site #51.

Graph #4, Distance Traveled vs Source, showed that the supported unit at node #17 would have to travel slightly less distance if it were assigned totally to water site #57 which does have some excess capacity. See Figure 5, Chapter III, page 28. It would have to travel significantly less distance if it were to be served entirely by either water site #11 or 12. Since both 11 and 12 are already at full or nearly full capacity, only a forced assignment to water site #57 is feasible with the existing site capacity limitations. A request for numerical analysis and subsequently item #4, Supply Source Change, allows one to see effects of forcing supported unit #17 to get all of its supply needs from water site #57.

Upon the completion of the reoptimization, the results of this forced assignment can be readily seen by again requesting graph #1. Supported unit #59 is now served by water point #39 which was previously not utilized. Additionally, graph #3, shows that unit #17 still must travel further than anyone else to statisfy its demand. The conclusion is that a forced change of the supply source for unit #17 is not advantageous.

After deleting water sites #31 and 39 from the candidate list the flow is computed again. As expected all water sites are now being utilized. Also, since water sites #11, 22 and 47 are only partially utilized they could be operated at the sustained production rate of 100 GPH.

#### Conclusions

#### Solution of the Test Problem

After collecting the personnel strength data and entering it along with the road network an initial feasibility check was conducted. It was found that even with all 14 wells in the Division area operating at the sustained capacity there was insufficient water available. To satisfy the demand the water supply of all wells was increased to the highest production rate allowed. This is a realistic problem solving approach and was incorporated into the DSS by converting the 10 - 12 hour capacity to that of an average GPH capacity for 24 hours. The conclusion is that 12 water point equipment sets are needed to open and maintain the 12 water sites needed to satisfy the demand. Another solution would be to have one equipment set ser-

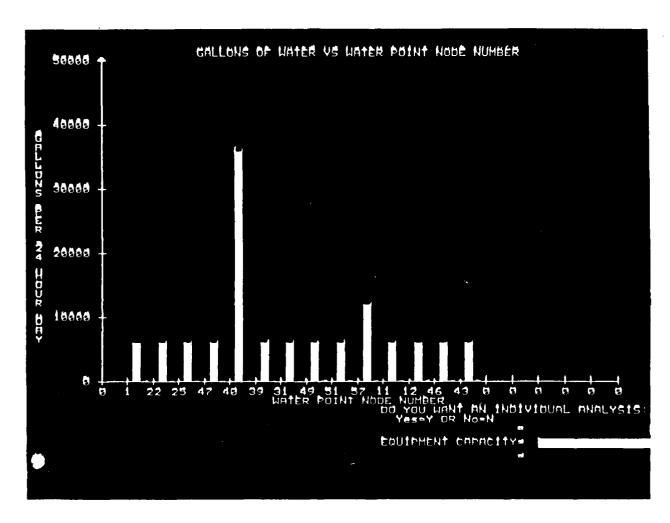


Figure 15. Forced Supply of Unit #17 from Water Point #12

vice two wells that are near to each other by employing its storage capacity and shuttling between two sites every 10 - 12 hours.

Since this case problem was prepared by instructors at the U.S. Army Engineer School, it is felt that its intent was to force all officer students to reach the same conclusion. As a training vehicle the students would learn that water resupply cannot be taken for granted as is usually the case.

The solution procedure is so flexible that the user should quickly feel at ease. This will insure that other uses will be found for the DSS demonstrated here, e.g., locating the best railheads to utilize in a combination railroad truck transport problem, choosing the location for ammunition resupply points, or selecting the location for the combat engineer's barrier material prestock points.

#### Solution Time

The second second

The following response times were measured for the 60 node case problem involving 19 supported units and 14 water points:

Background road network input: 30 minutes

Water Point Capacity Data: 2 minutes

Combat Unit Demand Data input: 4 minutes

Computation of Shortest Paths: 30 seconds per water site

Computation of Initial Solu.: 30 seconds

Computation of Optimal Solu.: 10 seconds per iteration

Analysis of the Results: 15 minutes

For larger problems all of these times would increase linearly with the number of nodes in the problem.

### Recommendations

The following areas are presented here as potential enhancements of this prototype:

### Digitized Map Input

- (1) A more efficient data base structure to receive input from the digitizer pad is required. This would facilitate the use of several times as many nodes. Specifically, a linked list could easily be used here; arrays NS, NT and AL could be directly generated from the digitizer pad using a small amount of scratch storage.
- (2) Considerable modification of the digitizing routine is needed to allow for the correction of mistakes while tracing the map. (An actual implementation would require that maps be predigitized on disks and available much as maps are now.) The digitizer would only be used to update the data on the disk based upon newly constructed roads. This predigitized map could conceivably include coded information as to classification of the different size roads.
- (3) An addition of the military map reference grid to the screen would facilitate the input of both supported unit locations and potential water point sites.
- (4) Standard military unit symbols could be depicted on the screen instead of node numbers to improve user orientation.
- (5) A subroutine to permit the appending of adjacent map sheets by compressing the picture would significantly increase the versatility.
  - (6) The need to store a large picture file, 300 sectors, on the

disk could be eliminated if the road were stored as a series of arcs.

This would then require only the storage of the end point coordinate pairs for each arc segment. This could perhaps be implemented by having two types of nodes.

The primary nodes would be recognized by the program as potential locations for water points, supported units and road intersections. The secondary nodes would only be used by the program to plot a representation of the road network. This would preserve user orientation and thereby supplement his subjective evaluation of alternative sites.

(7) An alternative means of entering the network could be by using the keyboard to specify the beginning node, ending node and distance. A preliminary implementation of this exists now by selecting the ADD NODE/ARC menu point with the light pen.

#### Supply/Demand Data Input

- (1) Alternative means of entering the node data would simplify the initialization of the problem. For large numbers of nodes the switching between the light pen and the key board is awkward.
- (2) Another interrupt routine could be set up to simplify the return to light pen control of the menu while in the node designation subroutine.
- (3) The ability to have dynamic dimensioning of the number of supply points and water points in the problem would help the user feel more comfortable with the DSS.
  - (4) The overall color scheme of the network could be modified

so as to easily distinguish water points from the supported units, and both of these from the road intersections. Possibly the DSS should display no numbers by any of the nodes unless they are designated as either a supported unit or a potential water point site. The resident intersections could be made the same color as the road to decrease clutter on the screen.

- (5) It would be possible to store on the disk typical unit strength data and consumption data available for recall without consulting reference texts.
- (6) A rearrangement of the data structure would also permit the collocation of supply points and demand points.
- (7) A procedure for allowing the deletion of either water points or supported units from the candidate lists without having to re-enter all of the capacity and demand data is needed.
- (8) The user should be able to recall, at any time, the data and the current solution.

#### Display of the Analysis

- (1) The sensitivity analysis could be supplemented by heuristic optimization routines. [36,17,35] Also the possibility of calling on a host computer for an exact solution could be provided if appropriate communications channels were available.
- (2) The scales of the graphs could be color keyed to the results and multiple scales plotted for each set of values.
- (3) Simulated closing of a water point could be permitted by assigning all of its costs to the simulated infinity value of 32,000.

The "what if" effects of closing a water point could then be analyzed without returning to the CHANGE SUPPLY/DEMAND subroutine.

- (4) The graphical results could be highlighted to bring out notable information, such as sites not used.
- (5) A "HELP" subroutine could be implemented to explain each graph if the user is unfamiliar with the display.
- (6) The availability of a procedure by which the user could identify the density of traffic on a specific arc would aid in preventing congestion on the road network.
- (7) A subroutine to automatically weight the transportation algorithm cost matrix to favor supported units traveling excessive distances is needed. This could be accomplished by squaring all shortest-path distances in the matrix, or by setting any distances in excess of a predetermined maximum to infinity. The latter method would then prevent travel between those respective points whose distance has been set to infinity. Of these methods, the former would be more desirable due to its global effect on all supply transactions.
- (8) By reducing the size of the graphs, all four of them could be displayed on the screen simultaneously to aid in their quantitative comparison.
- (9) Maranzana's hueristic [31] would be particularly adaptable to this program's organization. It would be employed to select the sites that should be closed.

## Overall DSS

(1) The color coding of all messages could be standardized to

increase the user's recognition of the response needed.

- (2) The number of interrupt routines could be increased to handle errors that users are likely to make.
- (3) Improvements in the specific wording of prompts could be implemented to decrease user irritation and increase intuitive understanding. A user experiment should be conducted to identify potential improvements.
- (4) There are several possibilities for the distribution of this information to the supported units once a decision has been made. A printed copy of the actual supply sources with respective demand destinations could be provided on the standard line printer. By connecting the Chromatics terminal to a Xerox color copier, either paper copies or transparencies of any picture on the screen could be generated for distribution to supported units.
- (5) The standardizing of the blinking throughout the program and perhaps its total replacement by a throbbing action would increase user orientation and decrease user irritation.
- (6) A global refinement of this prototype is needed in order to bring it into line with the required consistency standards of a DSS, e.g., color usage, data input/output, user action minimization, and identifiability of user required actions or choices.

#### APPENDIX I

#### ASSUMPTIONS (A) AND THEIR JUSTIFICATIONS (J)

- (i) A. An engineer reconnaissance has been conducted.
  - J. This is a routine engineer function.
- (ii) A. The cost of water resupply is minimized if travel distance is minimized.
  - J. All relevant costs increase as the travel distance increases.
- (iii) A. Unit demands and water point output are based on a 24-hour day.
  - J. Supply levels within the theater of operations are based on days-of-supply. One day-of-supply is a 24-hour operating day.
- (iv) A. All water sites are located on or near existing roadways.
  - J. Ease of access is a prime consideration in siting a water point.
- (v) A. All distances are determined from maps in equivalent units of measure.
  - J. Maps are available and give scaled representations of distances.
- (vi) A. Each unit's demand for water is known.
  - J. Consumption rates per man and per vehicle are published in Army Technical Manual 5-100. Unit vehicle and personnel strengths are available from other Divisional Staff Officers. Within the operational area, consumption rates are adjusted to reflect most recent demands.

- (vii) A. Capacities of all potential water sites are known.
  - J. Information would be available from the reconnaissance reports. See Appendix II for example reconnaissance report.
- (viii) A. The number of available water point teams is known.

- J. The Division Engineer knows how many water point teams he has. Additional teams can be requested from higher headquarters. Each team consists of a group of soldiers with appropriate water equipment sets to extract potable water from a water source.
- (ix) A. The production capabilities of water point equipment sets are known.
  - J. Equipment capabilities for authorized equipment is available in Army TM 5-100. See Appendix IV.
- (x) A. All water point teams have a storage capacity.
  - J. Each team has three storage tanks, each with 4,500 gallons of available capacity. See Appendix IV.
- (xi) A. The capacity of each unit for water resupply is known to be 400 gallons per trip.
  - J. The only organic equipment for the bulk transport of potable water within divisional units is the 400 gallon water trailer. Each trailer is towed by a truck.
- (xii) A. Round trip distances are more critical than one-way distances.
  - J. To effect water resupply, a trip must be made from the unit to the water point and back to the unit.
- (xiii) A. Every time a unit conducts a water resupply trip, it acquires a full 400 gallon trailer of water.
  - J. It would not make sense to make a complete round trip for a lesser amount of water merely to make up the remainder of a unit's allocation. This results in the demand of each unit being rounded up to the next highest integer number of trips required to satisfy it. Likewise the capacities of each water

point are rounded <u>down</u> to the next lowest integer number of trailer loads that it has the capability to supply. (This may not be feasible if large capacity transport equipment were employed.)

- (xiv) A. Any water site with an extremely large water capacity may be considered as multiple separate sites located side by side. Each capable of becoming water points.
  - J. Such a site will normally occupy a large area of terrain, and therefore be capable of accepting more than one water equipment set.
- (xv) A. There is no fixed cost for opening a water point site.
  - J. Costs are "sunk costs". The equipment and personnel are on-hand and are assigned only the water point mission. They are not available for other missions. All other criteria for choosing one location over another will be taken into account by the users' interaction with the program.

## APPENDIX II

ENGINEER RECONNAISSANCE REPORT AND WATER RECONNAISSANCE REPORT

The examples that follow were taken from reference [18], pages 18, 19, 20, 21, and 22.

1	INGINEER RECOMMAISSANCE	REPORT	
	(TM 5-700)	Table 1	PAGE / OF / PAGES
TO:	P // //	FROM:	27 M F D.
	Engr. Bn		. 32 nd Engr. Bn
FILE NO.	PARTY LEADER (Name,	Grade, Organization	) PLACE - HOUR - DATE
HS 47	C 15T / 1	. U . U . C .	C- 107254 - 07070
REPORT NO.	Smith ISTLA	ng the CO	Cq. 187256 - 070700
/	32 Tel Eng	. Bn	<i>OCT.</i>
MAPS			
Fran	ce & Belgium;	1944; 1:50,	000 Sheet 3855 IIN
DELIVER TO (	rganization, Place, Ho	our and Date)	
32 <sup>nd</sup> E	ingr Bn, St N	licholas, 07	1100 Oct.
8	ADDITIONAL REMARKS	47	uantity: A = 2 sq. ft.
	Farm Build	ings -	V=30 fpm.
OBJECT OBJECT TIME OBSERV		3 口!口	Q = 60cfm, 450qpm
_	T <sub>A</sub>	<i>}</i>	<del>_</del>
D   W.  0835  Y			Quality: slight turbidity
	DIWIIG	{	no odor
	Ser.		) possible pollution
			bivouac from nearby
	- Lander	<i>are</i>	1 6(1 771 3
	X	<b>~</b> )	pH = 6.8
		¥~~~	Chlorine demand=2pp
	1		<i>'</i>
	Blev Creek	- 450 APM	
	Creek	450 9Pm	
	Communications		h good drainage runs
		to Ist Inf area. No	of used for division suppli
		Turnout at wp m	ust be constructed.
	Cu Cu lilia	, ,	
	Site Conditions:	good concealme	ent, no targets in
1 1 1		vicinity ground	d slopes gently
		Trom road to	stream, good drain
		age banks, 3'	nigh, sodaed.
		Grove of trees	d as parking area. or farmhouse can
		be used as bive	ouac for w.p. personnel
	Rating:	Excellent w.p. :	
		EER WORK ESTIMATE	ON OTHER SIDE
TYPED NAME, G	RADE AND ORGANIZATION	SIGNATURE	11 711.11-
Norman H. Hq & Hq 3	Wells Capt. 2 Eng Bn	//arma	a H. Wells
DA Form 1711-		Edition of 1 May 56	

Reconnaissance reports must be carefully prepared and available on time. The information presented must be legible, clear, complete, and

concise. All information should be printed. DA forms 1711-R and 1712-R will be reproduced locally on 8 by 101/2-inch paper.

Figure 5. Engineer reconnissance report form—back of form.

		<del></del>			
WATER RECONNAISSANC (TM 5-700)		85	960	PAGE / OF 3 PAGES	
TITLE NUMBER REPORT NUMBER	REPORTED	BY (Hame	- Grad	le - Organization)	
FORWARDED TO S-4, 3					
1. LOC	ATION OF W	ATER SOURCE	E		
To Belione & Visinity, 1:2	5000	COORDINAT	ES 5	16723	
2. TYPE OF SOURCE (Check of	ne) / Ot	her (spec	1 <b>1</b> y)	LOCAL NAME OF SOURCE	
Stream Lake Pond	Sprin	E		ACCOTINE CREEK	
Well Reserv	oir		. ]		
3. DATE AND 4.		YIELD			
HOUR INSPECTED DEMEDIATE		TDIATE (gp	m) (G:	ive work estimate)	
08 1460 60 1250	<i>&gt;</i>	17,00	0	108 Man 40025	
5.	QUAL	ITY			
COLOR	ODOR		TAST	<del>.</del>	
CLELR	Non			Muony	
TURBIDITY (estimate)	DH TEST		CHILOF	CIME DEMAND TEST (ppm)	
Less than 50	7.5			3.5	
POSSIBLE SOURCE OF POLLUTIO					
Auche					
6. COMMUNICATIONS					
DISTANCE TO ROADS RAILROADS BRIDGES					
CONSUMERS 10 MI GOOD Nove Nove					
7. SITE CONDITIONS (If m	unicipal s	ystem, use	Items	9 and 10)	
SECURITY DIERLEAD CONCELLMENT GOOD. SECURITY AGAINST					
diagnal attract most the headises.					
DRAIMAGE					
Good					
BANKS (If surface source)					
STRRIE & SLOPING - ABOUT 3'HIGH					
DISTRIBUTION FACILITIES (existing)					
Nous					
8. SKETCH OF AREA (Show road net and traffic circulation) (Use reverse					
side for additional sketches, if necessary)					
]					
Sas 9		_			
585 8	241484	₹ 2,0E	•		

9. SKETCH OF WATER POINT (Show proposed set up for immediate operation. If water point is a municipal system, include sketch of system) (Use reverse side for additional sketches, if necessary) 452 O Raw WATER PUMP. 1500 GPH WATER PURIFICATION UNIT. @ CLERR WELL (STORAGE TRUKS). (4) Distribution rump w/nozzess. 10. DESCRIPTION AND SCETCH OF PROPOSED DEVELOPMENTS (If municipal system, include survey) (Use reverse side for additional sketches, if necessary) @ PROPOSED TURNOUT (APPROX. 75 METERS LONG) B STANDPIPES FOR DISTRIBUTION Note & See whereing histor in you !!

Page 2 (DA FORM 1712-R)

11. WORK ESTIMATES					
		ATE OPERATION			
TASK  O Conspect  Tuenous  Light clear  ing & grubbing  2- Haun &  spread gran  kellenge	MAN-BOURS  94	O Sq moneer  D-7 (Dozen)	40 cubier yords of grave!		
@ Setup equipment.	6	1500GPU Mobile water purifica. tion unit	Nove		
TASK	FOR DE MAN-HOURS	VELOPMENTS EQUIPMENT	MATERIAL		
3 Stand- pipes	4	1) Pipe wreneles  E) Haumer  3 Sacu	6 2 pipe - 1 pe. 8' long and 1 pe 2' long B 2" 90° Elbow, 2 a.e. B) 2" x 4° lumber 6' long - Zeau 6' long + Zeau 6' long th of 2" eanves hose with dispribution moggle. Note: Magenal for 1 au equal- pipe.		
TYPH OR PRINTED NAME  Wolfer J. A.	lewmans	SIGNATURE Status	L. Hewmon		

Page 3 (DA FORM 1712-R)

## APPENDIX III

# WATER REQUIREMENTS; WATER SUPPLY AND DESTRIBUTION EQUIPMENT

The following tables were taken from reference [18], Appendix B, pages 141, 142, 143, 144, and 145.

Table 1. Daily Water Requirements

1	2		3	4
			per unit er per day	
Unit consumer	Conditions of use	Temper- ate/cold climate	Desert/ jungle	Remarks
Man	In combat: Minimum	1/4-1	12_3	For eating and drinking only, periods not to exceed 3 days.
	Normal	3	13-4 46	When field rations are used. Drinking plus small amount for cooking or personal hygiene.
	March or bivouac Temporary camp	5	*5	Minimum for all purposes.  Desirable for all purposes (does not include bathing).
	Temporary camp with bathing facilities	15		Includes allowance for water- borne sewage system.
	Semipermanent camp Permanent camp	30-60 60-100		bothe actuage ayateur.
Vehicle Locomotive (steam)	Level and rolling country.  Mountainous country.	1/8-1/2 %-1		Depending on size of vehicle.  Depending on size of vehicle.
Locomotive (steam)	Standard military Commercial	Variable	}	150 gallons per train-mile.
Hospital	Drinking and cooking	Variable 10 per bed		200 gallons per train-mile.  Minimum; does not include bathing or water for flushing.
	Water waterborne sewage.	50 per bed		Includes water for medical personnel.
Impregnating plant, cloth- ing, M2A1.	Maximum impregnating capacity.	2,400		Aqueous process. Includes 2,000 gailons for plant operations and 400 gallons for washing and cleaning purposes.
QM bakery company (mobile).	Two 10-hour shifts	2,600		Water for making bread and cleaning baking utensils.
QM laundry company.	Two 10-hour shifts	64,000 (4,000 per unit.)		

<sup>1</sup> For unacclimatized personnel or for all personnel when dry bulb readings exceed 106°F, in the jungle.

Table 1. Daily Water Requirements-Continued

1	2	1	)	•
		Gai pe Consumer		
Unit consumer	Conditions of use	Temper- ate/coid climate	Desert/ jungle	Remarks
QM clothing exchange and bath company.	Two 10-hour shifts	360,000 (60,000 per unit.)		
Truck-mounted 400-gallon decontaminating apparatus.	Decontamination	4,000		Water obtained from natural source when available.
Chemical base laboratory, M2.	Normal laboratory work.	300		

Table 2. Quality and Quantity of Water Needed by Construction Equipment

Equipment	Rise	Quantity	Purity of Water
Rock Crusher	76–T	22,500-45,000 GPH*	No special purification. See water usable.
Rock Crusher	225–T	100,000-200,000 GPH*	
Concrete Mixer	16S	700 GPH	Potable; minimum of organic matter.
Concrete Paver	34E	3,500 GPH	Acid, alkali free. Sea water may be used, but decreases concrete strength
Central Mix Plant	1128	4,800 GPH	by 20%. Extra cement may be used to offset this effect.
Asphalt Plant		1,000 GPH	Alkali free, low sulfates.
Steam Jenny		850 GPH	Potable; low calcium and magnesium.
Steam Boiler (No condensate return).	200 hp	2,000 GPD	
Three Car Heater (for asphalt plants no condensate return).	52 hp	200 GPH	
Water Distributor	1,000 gal	1,000 gal/100 yds of 8' road	No special purification. Salt water ac-

<sup>\*</sup> Gallon per hour (GPE) requirement for rock cruchers is 8 to 10 times the number of cubic yds/hr. This is dependent upon type of aggregate and amount of sand.

Barel indie er an er an Eller bereiter eine bei er

Table 3. Water Supply and Distribution Equipment

s. Water Squipment lessed to Engineer Units.

7		Water transport equipment									9-2,000 gral		3.9 000 9.5	
11		Max tion	ê. S	2,400	2,400	7,500	900,	3,000	3,000	2,400	27,000	3,000	12,000	
10		Total Storage Capacity	į	6,000	9'000	009 21	18,000	000'6	000'6	6,000	81,000	000	36,000	
•		£	Part	01	9	ន	ĸ	ĸ	**	01	23	2	2	
80	Pump	8/M40)	Discrib	3	8	126	321	125	126	8	125	128	8	
<b>L-</b>	g 2		Capacity (gal)	1,500	1,500	4,500	4,500	4,500	4,500	1,500	000,6	900,6	000'6	
•	Rquipment in .ach set	Tagks	Number	**	n	00	•	**	69	ø	•	•	•••	
so.		Chemicals required (1b/br) <sup>3</sup>		0,1	91	2.4	2.4	7.7	2.4	1.0	4.7	7.7	÷.4	
•		Generator (kw)		*	m	91	97	10	2	**	2	16	92	
		Type parif unit; fresh water (GPH)	-	600 (420)*	600(420)*	1,500	1,500	1,500	1,500	600(420)*	3,000 (mobile)	3,000 (base)	3,000 (base)	well drilling
64		N a ge		م	۵	10	10	84	64	64	•	-	•	01
-		Usit		Airmobile div engr ba	Abs div engr ba Arme, inf. & mech div engr	•	Engr combat bn, army	Ingr const be	armed, inf. or mech	atrhorne	MS 80	Water purif team (GF)	Water purif team (GG)	Well drilling team (GE)

4 Much and can equip one water point.
2 Mach and an admitted of a graphia (red 00 bours of operation: 1/16 of supplies transported with each mobile unit.
6 One pump at steady peridection rate: others at fall rated expectly for distribution (intermittent operation).
4.8 discussed in paragraph 20 this unit is subject to change.

able 3. Water Supply and Distribution Emission Continued

b. Distillation Units.

1	84	89	7	w	•	-	80	6	10	11	12
į	Disti	Distillate capacity	Economy 1b	Pael	Pael required	E				Dimensions	
	ОРВ	GPD 1	tael for 15 of distilled	Type	Bd9	water required (GPR)	Mounting	Wright (ib)	Leagth	Width	Heipt
Therms compression	150	3.000	150	Sandina.	7	Ş	Trailer	6,700	14'-5"	8,-0,	8,-0*
					3	8	akid.	3,200	8'-11"	#J#	6.3.

\* The distillate expectly in GPD is based on a 20-bour operational day.

Table 3. Water Supply and Distribution Equipment—Continued

#### c. Water Distribution Equipment.

1	2
Beuipment	Capacity:
Trailer, cargo, 1½-ton, 2-	
wheel	60 cans filled
Trailer, tank, water, 2-wheel	400 gal
Truck, cargo, 21/2-ton, 6 x 6,	
LWB	100 cans filled
Truck, tank, water, 21/2-ton,	
6x6	1,000 gal
Strir, tank, water, w21/2-ton	_
trk track or	2,000 gal
Unit kitchen	5-gal cans, wt 50 lb (filled).

#### d. Capacities of Other Water Supply Equipment.

1	2
Equipment	Capacity
Deep well pumps:	
Helical rotor-type	60 GPM against 250-ft head.
Turbine type, 6-inch	200 GPM against 200-ft head.
Percussion well drilling ma-	
chine .	6- to 8-inch well, 1,000 to 500 ft.
Rotary well drilling machine	4- to 6-inch well, 350 to 150 ft.
Rotary well drilling machine	4- to 6-inch well, 1,500 to 1,000 ft.
Surface pumps, centrifugal type gasoline engine drive:	,
2-inch suction and dis-	
charge	125 GPM at 50-ft head
1%-inch suction and dis-	
charge	65 GPM at 50-ft head



Figure 45. 600-gph W. P. U. setup for operation.

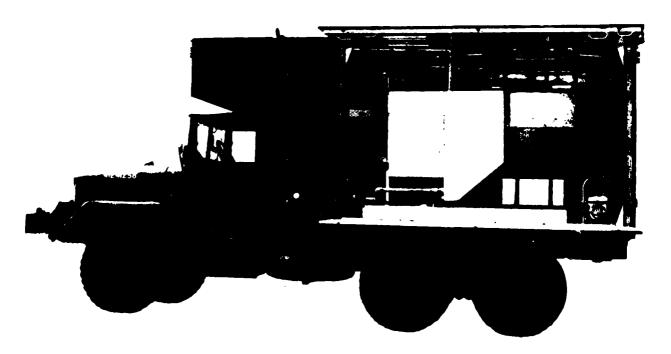


Figure 47. W. P. U. van type body mounted 1,500-gph.

# APPENDIX IV

# PROGRAM NTRACE

Program <u>NTRACE</u> accepts all input data for this prototype DSS.

It was written by Monty J. Anderson, CPT., EN, at Georgia Institute of Technology, Atlanta, Georgia.

```
'REPROMPT IF NULL ENTRY

DIM NN(30)

DIM NN(30)

'MR(0)=ACTUAL & OF NODES IN PROBLEH+NN(16)=HAXIMUM & OF NODES ALLOWED IN PROBLEH; NN(13)=FLAG FOR NEW COST MATRIX

'NN(1)=NN(4)=NH(2)=NH(5)=LOWER LEFT AND UPPER RIGHT X8Y BITPAD SCALING POINT COORD RESPECTIVELY

'NN(1)=NN(4)=NH(4)=NH(5)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH(4)=NH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              'INITIALIZE VARIABLES IF NOT CHAINED FROM COMPUTE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           900 CLEARIDE FINE BORDING AT ALLIANGUS AND ALGORITE CHAINED FROM COMPUTE 100 CLEANINE FINE BORDING ASSOCIATION AND ALGORITE CHAINED FROM COMPUTE 120 PRINT CHAINED FROM CHAINE
                                                                                                                                                                                                                                                                                                                                                                                  'CHANGE SUPPLY/DEHAND IF CHAINED FROM COMPUTE 'MINOR RESTART IF CHAINED FROM COMPUTE 'MAJOR RESTART IF CHAINED FROM COMPUTE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              IF LEFT#(Z#,1)="Y" THEN GOSUB 2700;GOSUB 840;GOTD 1000 'RETRIEVE STORED DATA
PRINT CHR#(12); GOSUB 2100
PRINT CHR#(27); R1C*;CHR#(27); GES*;CHR#(27); "IES*; ESTABLISH COMMUNICATIONS WITH BITPAD
ON A ROAD NETWORK
                                                   IF BI AND B2 THEN B1=0182=0:GOSUB 840:GOTO 4300
IF B1 THEN GOSUB 840:GOTO 4850
IF B2 THEN GOSUB 840:GOTO 4710
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320 PRINT 'IF YOU DO MOT HEAR A BELL THEN YOU ARE OUTSIDE OF THE SENSITIVE AREA '
320 INVUIGABLY, 'FESTIF F8-1' DECREASE THE SIZE OF THE AREA 'OB FRA-6D' '
320 INVUIGABLY, 'FESTIF F8-1' OF F8-3' OR F8-3' OR F8-8' THEN NHI)>"XINN(4)-Y ELSE SON SON INVUIGABLY, 'FESTIF F8-1' OR F8-3' OR F8-8' THEN NHI)>"XINN(4)-Y ELSE SON SON INVUIGABLY, 'FESTIF F8-1' OR F8-8' THEN NHI)>"XINN(4)-Y ELSE SON SON INTO OF THE SCALE POINT. LISTEN FOR A BELL. 'UNOISES'C6'
320 PRINT '"YESTIF F8-1' OR F8-3' OR F8-4' OR F8-8' THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF THE AREA TO BE TRACED.'; 'S F8-8' OF F8-8' OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF THE AREA TO BE TRACED.'; 'S F8-8' OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF F8-8' OF THE AREA TO BE TRACED.'; 'S F8-8' OF F8-8' OF THEN NHI(2)-XINN(5)-Y ELSE GOO SON OF THE AREA TO BE TRACED.'; 'S F8-8' OF THE AREA TO THEN NHILE.'

400 PRINT 'UNCATANY THE OF THE AREA THOU ARE NOW READY TO INPUT THE THEN THE OF THE AREA THOU HAVE FRINGED.'

400 PRINT 'UNCATANY THE OFFICE ALL'CA ROAD INTERSECTIONS"CE AND ROAD ERA.'

400 PRINT 'UNCATANY THE OFFICE ALL'CA ROAD INTERSECTIONS"CE AND ROAD ERA.'

400 PRINT 'RESTORATE OFFICE ALL'CA ROAD INTERSECTIONS"CE RE TO ENTER AS MANY NODES ';

400 PRINT 'RESTORATION THE CANADA THE NODE WAS ACCEPTED AND A'CLI BLUE'CA ';

400 PRINT 'RESTORATE OFFICE ALL'CA ROAD INTERSETING THE AS MANY NODES ';

400 PRINT 'RESTORATE OFFICE ALL CANDED INTERSETING THE AREA TO DIGITIZE ROUTINE

400 PRINT 'RESTORATE OFFICE ALL CANDED OFFICE TO ENTER AS MANY NODES ';

400 PRINT 'RESTORATE OFFICE ALL CANDED OFFICE THE AREA TO DIGITIZE ROUTINE

400 PRINT 'RESTORATE OFFICE ALL CANDED OFFICE TO ENTER AS MANY NODES ';

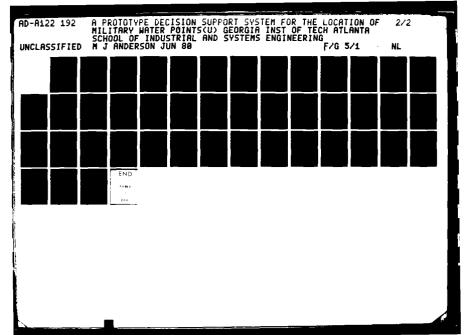
400 PRINT 'RESTORATE OFFICE ALL CANDED OFFICE TO ENTER AS MANY NODES ';

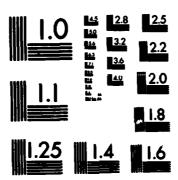
400 PRINT 'RESTORATE OFFICE ALL CANDED OFFICE TO ENTER AS MANY NOTES ';

400 PRINT 'RESTORATE OFFICE ALL CANDOO OFFICE AND THE 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         'REJECT INPUT IF ZERO
'SCALE BITPAD COORD TO SCREEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       'ACTIVATE LIGHT PEN INTERRUPT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          'SESTHIS IS THE INFINATE LOOP SECTION TO WAIT FOR A LIGHT PEN HIT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              1010 TR=110M ERRORGZ GOTO 2000!DUT&H90.0
1020 PRINT CHR6(27)*DA1"C6LIGHT PEN ACTIVATED"C7"K*
1030 PRINT CHR6(10)+CHR6(27)+"DA0"K*+
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     GOT0 1040
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         1040
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      8
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MICROCOPY RESOLUTION TEST CHART NATIONAL BUREAU OF STANDARDS-1963-A

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'IBNOR ALL LIBHT PEN HITB
'RECEIVE LIGHT PEN HIT CDORD
'IF HT<>1 THEN BRANCH TO APPROPRIATE SECTION
'SEARCH THROUGH HENU FOR CLOSEST POINT
                                                                                                 'IGNOR NODE REQUEST IF DISTANCE IS < 5 DOTS
                                                                                                                                                                  'REJECT COORD IF OUTSIDE SCALED AREA IF BLUE BUTTON THEN ESTABLISH A WODE IF GREEN BUTTON THEN DRAW AN ARC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                'SESTMIS SECTION CONTROLS THE BRANCHING TO THE APPROPRIATE SECTION AFTER A LIGHT PEN HIT
If Err-24 Then 2010 ELSE ON ERRORGO GOTO 0 'TAMAB ALL LEGAL MED HATE
                                                                                                                                      'RECORD NODE COORD! PLOT ON SCREEN
                                                                                                                                                                                                                                                                                                                                                                                                                                                'SUM DISTANCE FROM LAST COORD
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                *$$$THIS SUDMOUTINE PLOTS THE NODE MUNDER AND A CIRCLE AT THE NODES COORD
PRINT ""U-1:PLOT NX(CL),NY(CL)
PRINT CHR6(21);
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               'RECORD TWOUNY ARC
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               *## THE CLOSEST NODE TO THE LIGHT PEN HIT FOR J=1 TO AN(O)
DI=ABS(NX(J)-XP)+ABS(NY(J)-YP)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       IF CL<10 THEN PRINT USING .0.1CL! ELSE PRINT USING .00.1CL!
                                                                      IF XP<0 OR YP<0 OR XP>511 OR YP>511 THEW 1140
IF F4="4" THEW BOSUB 1400
IF F4="0" THEM BOSUB 1500
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      XP=CURGX(4):YP=CURGY(4)
GW WT BGTO 2040:3335,3835,3000:4100:4145
XD=25:FOR I=1 TO 4
                                                                                                                                                                                                                                                                                                                                                                                                                                                         8070 1580
8M-251808UB 1800
BM-251808UB 1800
BL-8U-8H1PLQT NX(CL),NY(CL)
PRINT"F"(C3T-11PLQT NX(C),NY(S),2
PRINT"F"(SEMF&(21)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            IF DI<SH THEN SH-DICL=J
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          8X(6,CL)=8U19X(CL,8)=8U18U=0
                                                                                                                                                                                                                                                                                                                                                                                                                    IF F6<> 8" THEN 1640 (D-XPIYO-YPISU-SU+DI
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THE REPORT OF THE PROPERTY OF

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"C4" 10X(8,T)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                NINT CHRCI2); "2; |
LINE INPUT:"C7D0 YOU WANT TO CHANGE A SPECIFIC ARC LENGTH"C5"17"2"C7 Yes=Y or No=N "J"C5:12;
LINE INPUT:"C7ENTER THE START NODE ="C5:181PRINT"
LEFTECAGE: C7ENTER THE START NODE ="C5:181PRINT"
Lebitabut:"C7ENTER THE FINISH NODE ="C5:181PRINT"
Lebitabut:"C7ENTER THE FINISH NODE ="C5:181PRINT"
LEBIT CHRCI2); "C7THE PRESENT "C4"IONEWAY"2"C7 LENGTH OF THE ARC FROM NODE; "C7TO NODE; "C7TO NODE; "C7TS:
PRINT "C4ENTER THE NEW BISTANCE."
                                                                                                                                                                                                                                                                              PRINT CHRO(12)!**X1.*Y1.*CGYOU MUST NOW ENTER THE INITIAL DATA TO BE USED "
PRINT'AS CONSTANT VALUES IN ALL SUBSEQUENT CALCULATIONS FOR PROBLEM: "C4.5A6
PRINT'*CATHE ONLY MAY TO CHANGE THE VALUES IS TO DO A"C? '"CAMINOR RESTART"C?'":PRINT MR(9)=0:118*TITE WATER CONSUMPTION PER MAN FROM"
MR(9)=0:118*TIT"CSAMIY"C? TH 5-700. APPENDIX B. TABLE 1. PASE 141"CS"J ")MR(9)
IF MR(9)<=0 THEN 2170
                                                                                              DUILBHYO.OTHERWE 1020
*SOUTHIE SECTION IMPUTS CONSTANT VALUES FOR CALCULATION OF CAPACITIES & DEHANDS
PRINT"*CATHE MAXIMUM NUMBER OF NODES MEMORY WILL ALLOW IS 40."
PRINT"*CHOW MANY NOBES WILL BE IN PROBLEM"C4 ";A$;"*C5"J";!MA~GIINPUT MA
IF MA'I OR MA>60 THEN 2110 ELSE NN(16)*MA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    THIS SUPPOUTINE ALLOWS FOR THE MANUAL CHANGING OF A SPECIFIC ARC LENGTH
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             "CARETURN."C4"J .
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 INTIPRINT' CSTRUCK CAPACITY MUST BE IN TERMS OF "C7GALLOMS"C3." (110)=01IMPUT' HOW MUCH CAN YOUR TRUCK HAUL PER ROUND TRIP"CS "FMM(10) TRIPTITY CS THEN 2200
INTIPRINT' CSMATER PURIFICATION EQUIPMENT SETS ARE"3.
INTIPRINT' CAMBLE BE HOUR"CS WILL THE ONES "3";
INTIPHOW MANY "C7GALLOMS PER HOUR"CS WILL THE ONES "3";
(115)=01IMPUT'YOU WILL BE USING PROCUCE"CS"; MM(15)
                            BI<20 THEN PRINT CHR6(7)110N I BOTO 4100,4200,4300,4400,4500,4600
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   WIT "C7A Cerrisse Return ALONE RESULTS IN NO CHANGE."1"C5:10%(6,1)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        10 PRINT THIS IS THE FILE SAVE ROUTINE, IPRINT
20 PRINT THIS IS THE FILE SAVE ROUTINE, IPRINT
20 PRINT THE SAVE DATA TYPE "CS' "ISTOP"Z' "C7 THEN "CARET
20 LINE IMPRINT ZOTO" "K" "WO, 1005110, "CCRC, 1200
40 PRINT CHRO(2); "060" "K" "W'0, 1005110, "CCRC, 120
40 PRINT THE SUBSECTION SAVES DATA WITHOUT PROMPTING THE USER
40 IF MN(7) THEN 2570 ELEE 250
70 DGS "ARTSAVE" +AA4-SE SK "105" ARTSAVE +AA4-IS IS"
80 IF MN(8) THEN 2590 ELEE 260
80 DGS "ARTSAVE" +AA4-SE SK"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               'SESTHIS SUBROUTINE RETRIEVES PREVIOUSLY SAVED DATA
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   THIS SUBROUTINE SAVES THE DATA INPUT
-ABS(XP-X0)+ABS(YP-50)
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received announced brackets, postudies population, configurally 1995.

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(7) THEN ERASE BRISSBIN SR(WK(7)+1)-IS(NN(7)+1):DGS-ARYLGAD "+A+"SR SR":DGS-ARYLGAD "+A+"IS IS" ELSE 2770 "*C4":FGR I=1 TO NN(7):CL=SR(1):BGSUB 1900:NEXT (8) THEN ERASE SKIDIM SK(NN(8)-1):DGS-ARYLGAD "+A+"SK SK" ELSE 2790 "*C1":FGR J=1 TO NN(8):CL=SK(J):GGSUB 1900:NEXT (8) THEN ERASE SKIDIM SK(NN(8):CL=SK(J):GGSUB 1900:NEXT (8) THEN ERASE SKIDIM SKIDIM SK(NN(8):CL=SK(J):GGSUB 1900:NEXT (8) THEN ERASE SKIDIM SK(NN(8):CL=SK(J):GGSUB 1900:NEXT (8) THEN ERASE SKIDIM SKID
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         MRACA2)#TERMEE BKIDIN BK(NN(8)+1)
MRACA3#WAGE BKIDIN BK(NN(8)+1)
MRACA3#WAGE PROBLEM 144; WOW WAS C4:1WK(7); "C7WATER POINTS ";
MRACA3#WAGE)#"C7WMITS NEEDING WATER."
MATTED YOU WANT TO CHANGE THESE WINDERS YearY OF No-N'C5"1;"Z"J ";Z6
#UZ641,""T THEN 3000 ELSE PRINT CHAS4(12)#
PUT"C7TD CHANGE THE "C2COMBAT UNIT"C7 LOCATIONS OR STRENGTHS "C2SMTER"C7 YearY OF No-N' "C5"1;"Z"J:;Z6
#UZ641,""T THEN 808UB 38001IF HT<>4 THEN 3040 ELSE PRINT"C2ALL COMBAT UNITS MAVE BEEN ENTERED."1030"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               JF"C7TD CHANGE THE "CAMATER POINT"CY LOCATIONS OR CAPACITIES "CSENTER"CY Yes"Y OF NO=N "CS"17"2"J:)26
[26:1]="Y" THEN GOBUR 330011F HT<>4 THEN 3010 ELSE PRINT"CZALL WATER POINTS MAVE BEEN ENTERED."K"1030"
[0]=[5(0]-EK(0)11F Q(0)>0 AND BK(0)>0 THEN 3130 ELSE Q=ABS(Q(0))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  'BET NEW STATEM 3320 'SET NEW SELECTOR & LIGHT PEN 'IGNOR HIT IF DISTUNCE > 25 DOTS
'OR J=1 TO MN(8):IF CL<>SK(J) THEN NEXT ELSE 3330 'IGNOR NODE SELECTED IF ALREADY A COMBAT UNIT HAG(2):P:000-C6-1:1:008UB 1900
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             18 SUBROUTINE CONTROLS THE IMPUT OF ALL SUPPLY POINT DATA
'INITIALIZE NODE POINTER
"AFTER EACH HIT ENTER THAT SITE'S MAXIMUM CAPACITY IN GALLONS PER HOUR.
"AFTER EACH HIT ENTER THAT SITE'S MAXIMUM CAPACITY FOR A "CEUATER POINT"C7.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      HIS SUBPOUTINE SPECIFIES THE NUMBER OF SOURCES AND THE NUMBER OF SINKS
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                (1) THEN IF NM(7)=SR THEN 3040 ELSE 3025 ELSE 3035
CHR0(27)+"DAO"C3*1:FDR I=1 TO NN(7):CL=SR(1):GDSUB 1900:Q(CL)=0:NEXT
CHR0(27)+"DA1"C7"+
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              1) THEN IF WH(8)=8K THEN 3070 ELSE 3035 ELSE 3045
CHR6(27)+"DAG"C3"+!FOR J=1 TO NH(8)!CL=SK(J)!GOSUB 1900!G(CL)=0!NEXT
CHR6(27)+"DA1"C7"+
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   16(12)) ""CABEMAND EXCEEDS SUPPLY BY"CA": 10; "2"CALDADS."
WAT OVER AND INCREASE SUPPLY OR DECREASE DEMAND. "C7:160TO 3010
(91)NH-WH (13) (HV-NH (17)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   RIERASE SR.181DIM SR(MM(7)+1),18(MM(7)+1)
NY UNITS ARE TO DE SUPPLIED! "C5"19K
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            "CS . 188
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        "CADELETE"C7 A SITE ENTER "C50"C7"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  OR HR(8) THEN DOS'ARYLOAD '+AS+'Q Q'
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   "CONDU MANY WATER POINTS ARE THERES
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 DIPRINT CHRS(12) ICHRS(7) FIRETURN
```

```
THE TOWN CHART CHREACES THE NAME OF THEM 3330 ELBE 3330

PRINT CHREACES TOWN THE THE SECON THEM 3330 ELBE 3330

PRINT TOW HART TERROR MEDICE THE MANNER OF CLAMER POINTS. **

PRINT TOW HART TERROR ABSILOANTE POINTS OF "CAMPER POINTS".

PRINT TOW HART TERROR ABSILOANTE POINTS OF "CAMPER POINTS OF "CAMPER POINTS".

PRINT TOW HART TO REDUCE THE MANNER OF WARTER POINTS OF "CAMPER POINTS OF "CAMPE POINTS OF "CAMPER POINTS OF "CAMPER POINTS OF "CAMPER POINTS OF "CAMPE POINTS OF 
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            IF NP-0 THEN PRINT--C3-;;608UB 1900KY-0 ELBE 3900
IF GCL, THEN FOR J-I TO MM(G):GK(J)-GK(J+1):WEXT:GCL)-0:5-8-1:60TO 3830 ELBE 8-8-1:60TO 3830
PRINT CHR:(27):GAI-K-C7UNIT AT NODEG-C4-;CL:-"C7NUST MAKE-C4:G1-"C7TRIPS PER DAY IF STRENGTH IS:"C4:1NP CHR:(27):GAO:
GCCL)-BIIF 8-NN(8) THEN IF 8K(0) THEN 3630 ELBE 3935 ELBE 3830
PRINT CHARLES): "CTTME PRESENT CAPACITY OF "CAMATER SITE"C7 NODE#C4: CTIS"C2: FOCE): "CTRUCK LOADS PER DAY."
"CPACALLENS PER NOUR CAPACITY
"CPACALLENS PER NOUR CAPACITY
"BECAPACITY PER 24 NOUR DAYS SINTEGER # OF MATER POINT EQUIPMENT SETS POSSIBLE
"PRINTERS # OF TRIP ANALARE FOR RESUPPLY FROM THAT SITE
"MECAPACITY PER 2390 ELSE CS-0:8010 3405
"FRINTERS TOO BLSE CS-0:8010 3405
"ASSIGN MINIMUM OF OME EQUIPMENT SET
"FILL SITE" CS-0:8010 3405
"ASSIGN MINIMUM OF OME EQUIPMENT SET
"FILL SITE" CS-0:8010 3405
"ASSIGN MINIMUM OF OME EQUIPMENT SETS
"FILL" CAPACITY CAPACITY SETS TO YOU MANT AT SITE" CA-1CL!" "C7. MAXIMUM-"C4-1SI)!INPUT" CS-1NEIPRINT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                RESI-CLII-E
F CP-0 THEN PRINT-C3:11809UB 19001KY-0 ELSE 3440
H-11F G(CL) THEN FOR J=I TO NN(7):88(J)-88(J+1):18(J)-IS(J+1):18EKTIG(CL)-0160TG 3330 ELSE 3330
H-17E CHOIST PRINT-C21A-C4-HEE BITE 0-C4:1CL:-C7CAN SUPPLY A TOTAL OF-C4:5CS:-C7LOADS PER DAY.:1PRINT
F GYCE THEN PRINT-C21F-C4:1SIS-C2EGUIPMENT BETS WERE USED IT COULD PROVIDE-C4:1G;-C2LOADS PER DAY."C7:
                                                                                                                                                                                                                                                                                                                                                                                                       / CMR6(27)# DAG*#1808UB 1900
<0 THEN IF 9K(0) THEN 3935 ELSE 3910
|=1 TO HH(8)!IF 9K(1)<>CL THEN HEXT ELSE $=$-1180TO 3890
```

```
16(12)) "J.C7YOU MAVE ENTERED CAPACITIES FOR C4.181 "C7UNITS.
                                                        "1"CSVES=Y OR NO=N"C7"2
               ON CONTROLS THE MENU SELECTION FOR THE CALCULATION OF FLOW
                                                                                                                                                                                                                                                                                                                                                             BOTHIS SECTION CONTROLS THE MENU SELECTION FOR THE BITPAD DATA INPUT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DUTINYO,DIRESUME 1020
'###THIS SECTION CONTROLS THE MENU SELECTION FOR THE INPUT OF DATA
PRINT CHR$(27)*"GA1*!CHR$(12)*!GOSUB 3000
PRINT CHR$(12)*"X2,"Z2,"C&SAVING DATA"X1,"Y1,"K*!GOSUB 2550
                                                                                                                                                                                                                                                                         RINT CHRO(12))CHRO(7);"PROBLEM "JAS!" MAS";HS(H+1);"ARCS."
RINT"-X2,"Y2,"CANDW SAUING DATA"X1,"Y1,";
DS"ARYBANE "+A6+"D DX:!DGS"ARYSAUE "+A6+"NS HS"
DS"ARYSANE "+A6+"NT HT:!DGS"ARYSAUE "+A6+"AL AL"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "TALL DATA HAS NOW DEEN ENTERED."2"C7"
PO.O:RESUME 1020 ELSE TR-1180TO 1000
                                                                                                                                                          WINT CHRO(27): DAI: SCHRO(12):
RINT "HOW COMPUTING LINKLIST DATA ARRAYS FOR PROBLEM:
RINT="CS=X002"Y002PLEASE WAIT="C2=X001"Y001"Y
"OR I=1 TO NIFOR J=1 TO N
F DX(S-J>0 THEN A=A+1:NT(A)=J:AL(A)=DX(I,J)
EXT J:NG(I+1)=A:NEXT I
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 Print Chre(27) Foal ( Fighe (12) F
Boold 2500 ( Frint - - - ) Chre(12) Ficleariend
                                                                                                                                                                                                                                                                                                                                                                                 EF FIFTK(X)=FIX(X-181(1))/181(3)+.5)
EF FIFFK(Y)=FIX((Y-181(4))/181(6)+.5)+100
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   4210
4220
4220
4230
4230
4120
4120
4120
4120
4120
```

CANAL STATE OF STATE

```
PRINT "C70-C51"C7" "CALLON RESTART"C7."

PRINT "C70-C52"C7" "CALLON RESTART"C7."

PRINT "C70-C52"C7" "CALLON RESTART"C7."

PRINT "C70-C52"C7" "CALLON RESTART"C7."

INTUIT "C70-C52"C7" "CALLON RESTART"C7."

INTUIT "C70-C52"C7" "CALLON RESTART"C7."

IF Z( OR Z>3 THEN 4000

ON Z 80T0 4490-4710-4800

ON Z 80T0 4490-4710-4800

ON Z 80T0 4490-4710-4800

ON Z 80T0 A490-4710-4800

INTUIT CHR6(Z2):"CALLON RESTART A8SIBNG A NEW PROBLEM NAME TO THE EXISTING DATA."

LINE INPUT-1"CSNOWNT"-">PRINT CHR6(Z2):"C7A MAJOR RESTART A8SIBNG A NEW PROBLEM NAME:"C5".

INTUIT CHR6(Z7):"CALLON PRINT CHR6(Z2):"G0T0 4800 ELSE PRINT "U0:1005110,"K:"CHR6(Z2):
                                                                                                                              ENTERED.
MAKIZ31""CTYNU CAN NOT COMPUTE FLOW UNTIL THE NODES HAVE BEEN DESIGNATED. YOU'
                                      1840 LINE IMPUT-"Z"CSENTER"C7 Certiede Return TO CONTINUE, "1251A5=55
1850 PRINT ""M9:1005110:";CHR:(12);""C7A "C2NINOR RESTART"C7 REDUIRE
1860 BOBUD 2140EPRINT-"="K";CHR:(12);NH:(7)=01NN(8)=01NN(13)=01DGS"RE
1870 BOBUD 840!PRINT CHR:(27);"OA1";CHR:(12);
1880 HT=1181=01BZ=011F TR THEN GUTSH90;01RESUME 1020 ELSE BOTO 1000
                                                                                                                                                                   UT EMPO, OIREBUNE 4570
DB CHAIN COMPUTE
```

Active Constitution of the Constitution of the

#### APPENDIX V

# PROGRAM COMPUTE

Program <u>COMPUTE</u> performs all calculations and controls the display of the result of those calculations. It was written by Monty J. Anderson, CPT., EN, at Georgia Institute of Technology, Atlanta, Georgia.

CONTRACTOR AND DESCRIPTION OF THE PROPERTY OF

```
'ROUND OFF TO NEAREST INTEGER FOR GRAPHING
MPUTE "WATEMOUSE LOCATION ON A ROAD WETWORK WITH INTERACTIVE GRAPHIC FOR BOCUMENTATION SEE MASTERS THESIS BY MONTY J. AMBERSOM, CPT. USA BETITUTE OF TECHNOLOGY, JUNE 1980. PROF. DOMOVAN YOUNG CHAIRHAN LOS(PO)/LOS(10).
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        AL(1) THEN 2040
MBE WE-NT-ALIBIN NB(MA+1)-NT(SBHA)-AL(SBMA)
B-ARYLDAB -+A6+"NB MB-:BDG"ARYLDAB "+A6+"NT NT-:BDG"-ARYLDAB "+A6+"AL AL"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        *885THIS SECTION CONTAINS THE INFINATE LOOP TO MAIT FOR A LIGHT PEN HIT TW-110M ERRORD 80TO 250010UTEM90.0
PRINT CHES(27): OAI-CALIGHT PEN ACTIUATED-C7-K:
PRINT CHES(10):CHES(27): OAO-K:1
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                BI-ABS(NP-XO)+ABS(VP-SO)
IF BI(20 THEN PRINT CHRS(7)+10N I GOTO 4100+4200+4300+4400+4500+4600
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         SSTHIS SUBPOUTINE RETRIEVES THE LINKLIST DATA ARRAYS WHEN NEEDED
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              BETHIS SECTION CONTROLS THE BRANCHING OF ALL LIGHT PEN HITS ERR-24 THEN 2510 ELSE ON ERRORSO GOTO 0 MT-0 THEN 2500
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    PESTHIS SUDPOUTINE FINDS THE CLOSEST NODE IN THE NETUDRK
                                                                                                                                                                             *SECTION SUBMOUTINE SETS THE MINDOWS AND DRAWS THE HEND
PRINT CHRO(27) + DA1"="K"U300,1005110,"R"GS-1CHRO(12) +
PRINT CHRO(27) + DA0"="K"C3"F"G" +
                                                                                                                                                                                                                                                     ((PO)=10"(INT(FM_(PO)+(FM_(PO)<0)))
((PO)=INT(PO+S+(X<0))
=0:80T0 4400
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           X(4)1YP=CURSY(4)
10TO 2540,2580,2580,2590,4150
10R I=1 TO 4
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             FOR JET TO MM(0)
BI-ABE(MX(J)-XP)+ABE(MY(J)-YP)
IF BICSH THEN SH-BIICL-J
```

CALCULATION OF THE PROPERTY.

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DETRIES SECTION CONTROLS THE NEW SELECTION FOR THE BITPAD DATA IMPUT

SIPPLINT CHRS(27); "CAIYOU MAVE HIT THE ADD HENU PT."

INT"—CATO AND A MODE, ADD AN ARC OR MAKE"

INT"—CATO AND A MODE, ADD AN ARC OR MAKE"

INT"—CATO AND A MCCANINGR OF PROBLEM-C2 ** 145; "C6 YOU MUST DO A "CCHINGR RESTART"C6."

INT"—TAYOUR TO WANT TO DO A "CAMINGR RESTART"C7! "1"C6Yes=Y OR No=N"C5"2: 126

LEFT$(25.1)="Y" THEN D1=1102"> ELSE PRINT CHR$(12):80TO 4180
                                                                                                                                    then "CSReturn."J"C4.;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       Telidutando dimegume 1010
Bastwis Mection Controls The Wenu Selection for the Stopping of Program Execution
Rint Dambels): Dolaw. Elemen(12): 1700 NAVE HIT THE STOP HENU PT.*
Bour 2000:Print="=":Chro(12):Chro(27): E:;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        440 FRINT CHR6(22)* GAI* CORS (12)*

440 IF NOT WR(13) TWEN BOBUR 54001PRINT COST MATRIX IC(1,J) NOW COMPLETE. *7030*

450 GBBUR 60001PAINT CHR6(12)*

460 IF TR THEN DUTBHPO.01RESUNE 1010 ELBE 1000

460 IF TR THEN DUTBHPO.01RESUNE 1010 ELBE 1000

500 ABSTHIS SECTION CONTROLS TWE NEW SELECTION FOR THE DISPLAY OF THE RESULTS

500 PRINT CHR6(12)* "GAI* FOR 12)*

524 PRINT "C7**C52.C7*" "C66ALLONS SUPPLIED US SITE **C7*"

525 PRINT "C7**C52.C7*" "C6AGST EFFICIENT SUPPLY PT. *C7*"

526 PRINT "C7**C52.C7*" "C6AGST EFFICIENT SUPPLY PT. *C7*"

536 PRINT "C7**C53.C7*" "C6AGST COSTLY COMBAT UNIT"

540 PRINT "C7**C55.C7*" "C6AGST COSTLY COMBAT UNIT"

540 PRINT "C7**C55.C7*" "C6AGST CASTLY CONTROL"

540 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

540 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

541 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

542 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

544 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

555 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

566 INPUT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

576 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

577 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

578 PRINT "C7**C55.C7*" "C6AGST COSTLY CONTROL"

578 PRINT "C7**C55.C7*" "C7**C56.C7*" "C7**C56.C7*" "C6AGST COSTLY C
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      IF A<1 OR A>5 THEN 4574
PRINTCHR&(12); "X2,"Y2,"C2PLEASE WAIT"C7"X1,"K"; CHR&(27); "DAO"WO,511511100";
SANES THE SHORTEST PATH MATRIX FOR THE CURRENT DATA SET
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         NATIVES SECTION CONTROLS THE NENU SELECTION FOR THE CALCULATION OF FLOW
                    B THE FILE SAVE ROUTINE. : IPPLIT

VE YOUR BATA-CLA' I TAPE-Z-C7 / '"CSSTOP-C7' then "CS!

T 26 <> STOP THEN 3070

THE SUBROUTINE SAVES DATA WITHOUT PROMPTING THE USER
14"NM NN"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 BESTMIS SUBMOUTINE PLOTS THE NODES AFTER A REFRESH OF THE PICTURE WINT ""C4" ! IFOR 1=1 TO NH(7)!CL=SR(1)!GOGUB 1900!NEXT
RINT ""C1" ! IFOR J=1 TO NH(8)!CL=SK(J)!GOGUB 1900!NEXT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   TEMPO-OSSESSIME 1010
SETHIS SECTION CONTROLS THE NEW! SELECTION FOR THE INPUT OF DATA
                                                                                                                                                                                                                                                                                                                                                             DE-ARYBAUE '+A6+'NK NK'
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PROGRAM SERVICES SERVICES SERVICES SERVICES

```
PRINT CHR6(27); DAG"NO.511511511"4"; CHR6(27); DA1"; CHR6(28);

IF LEFTG(27); DAG"NO.511511511 A. INDIVIDUAL ANALYSIS; Year OR NG=N"C5", "17"2"3"; Z6; PRINT CHR6(12);

IF LEFTG(20-1)="Y" THEN GOSUB 5:0016070 4500 ELBE 4500 ELBE 400.

IF LEFTG(20-1)="Y" THEN GOSUB 5:0016070 4500 ELBE 4500 REPLACED? Year OR NG=N"C5 "19"2"; Z6

IF LEFTG(20-1)="Y" THEN PRINT """""; CHR6(12); DGS"REFRESH "+A$:008UB 32001605UB 860

PRINT CHR6(27): "DAI"W"C7"; CHR6(12); DGS"REFRESH "+A$:008UB 32001605UB 860

PRINT CHR6(27): "DAI"W"C7"; CHR6(12); DGS"REFRESH "+A$:008UB 32001605UB 860

PRINT SECTION CONTROLS THE NENU SELECTION FOR THE RESTART FUNCTION
                                                                                                                                                                                                                                                                                                                                                                                                                       PRINT CHRS(27): "GAI: BCHRS(12);
PRINT CHRS(27): "CAMAJOR RESTART"C7.":
PRINT "C79"C52"C7"."CAMAJOR RESTART"C7.":
PRINT "C79"C53"C7"."CAMAJOR RESTART"C7.":
INPUT "C79"C54"C7"C70"C58"C7"."C70"C58"J: 12
IN Z
IN Z<
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        'SSETMIS SUBROUTINE DRAWS THE BRAPH-GALLONS SUPPLIED VS SOURCE NO.
I=01FOR S=1 TO NN(7):X(I)=8:Y(I)=0F(R(S)):RHK(IO):XN=X(I):YN=Y(I):NP(S)=SR(S):I=I+1:NEXT
T==8ALLDNS DF WATER VS WATER POINT NODE MUMBER.
Y==6ALLONS PER 24 HOUR DAY.
Y==6ALLONS PER 24 HOUR DAY.
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              "=I-1:PRINT""C4*9:8X=88:808UB S900:PRINT CHR8(27);"DAI";

""""1200080-12AUAILABLE CAPALITY"C7=*;

"PRINT""1200080-12AETUAL CANSURFITDW"C7=*;

PRINT"""1200080-12AETUAL CHR8URFITDW"C7=*;
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      P-P11IF P1<>0 THEN V12 HR(P)160T0 A810

K(1)=81XH=K(1) HR(A) V12 HR(A)

K(1)=81XH=K(1) YH=V(1) 11=1+11H=XT

Th="IBENTIFY THE WATER POINT THAT IS CLOSEST TO ITS CUSTOMERS"

VO="BISTANCE TRAVELED PER GALLON"
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                1(12) #: BORUB 5400 !PRINT "C2" #: 8X=774608UB 5900
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                AJFOR 8-1 TO MM(7)1Y(1)=18(8)SNN(10)1I=1+15NEXT
ST=1-15PRINT="C4=158X=6218DSBB 8900
mO1FOR 8-1 TO MM(7)1P=NU(8)1F1=NR(P)1XF=0
IF P=88 TNEM 4758 ELBE XF=XF+NF(P)
P=P11IF P1<0 TNEM P1=NR(P)180T0 4750
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        NT CHRE(12) #: CUTAHPO, OTREBUME 1010
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              1(10) II-I+11MEXT
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THE RESERVE ASSESSMENT OF THE PROPERTY OF THE

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"J"C5"1ENTER"2"C7 ITS NODE 4."C5"12
                                                                                                                                                                                                  CHRECIZ) FISHBUR SECOIPRINT "C2"FISK=771608UB S900IPRINT CHREC27) FOAL" F"U300060"C2LOOK FOR SMALL RATIOS."
F"U300060"C2LOOK FOR SMALL RATIOS."
FTHIS MEANS THE "C6MATER POINT"C2 IS CLOSE TO ITS CUSTOMERS."
                                                                    TESTHIS SUBROUTINE GRAPHS THE COMBAT UNIT THAT TRAVELS "XCESSIVE DISTANCE SOFTON Jel TO NN(8)!MP(J)=SK(J)
18-0158-J+NN(7):P=ND(8):P1=NU(8)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  T CHRE(27); "GAO"; CHRE(12); | GGGUB 5600!PRINT" "C5"; | SX=77; | GGGUB 5900 | X(0)-X2); XC)-X2); XC)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    ""F"C1"64";!PLGT X,Y,X+5.78!PRINT CHR$(21);CHR$(27);"DA1";
""U300080"C2CDNBAT UNIT"C7"";
                                                                                                                                                                                                                                                                                                                                                                                                                                                                  STHIS SUBROUTINE DRAWS A SUPPLY COST US SOURCE GRAPH
                                                                                                                                                                                                                                                                                                                                                                                  • "U300050"C4ALTERNATE. DISTANCES"C7=• $
                                                                                                                                                      P1>0 THEN P1=NR(P) 18-P160T0 4915
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            P1>0 THEN P1-NR(P) 18-P160TO 5040
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   CE TRAVELED"
ATIVE WATER POINT ABSIGNMENTS"
=N+NN(7):P=ND(S):P!=NU(S)
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AND THE PROPERTY OF THE PARTY O

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F P=0 THEN PRINT«"CYMATER POINT&"C6")23""C7IS NOT USED."1030"160TO 5100
RINT«"C7WATER POINT&"C6")21°"C78UPPLIES UNIT&"C2"18K(P-NN(7));" "C7WITH"C4")XF;""C7Gs1.$ PER DAY."
"P111F P1<>0 THEN P1=NR(P):XF=NF(P)$NN(10):G0TO 5148 ELSE INPUT-"C3CARRIAGE RETURN TO CONTINUE.")Z180TO 5100
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           PRINT."CZCONDAT UNITO.C3:Z}:"C7RECEIVE8"C4";XF!PRINT."C7Gal.s PER DAY FROM WATER POINTO.C6";0R(P)
P-P1:IF PI<>0 THEN P1=NR(P):XF=NF(P)&NN(10):G0T0 5178 ELSE INPUT."C3CARRÍAGE RETURN TO CONTINUE";Z1B0TO 5100
B08UB 5300:G0TO 5100
'setthis Bubroutine Provides Specific Numerical Data on Request Zeotprint Christopy, "Dat Jerreloop" in Christopy, "Dat Jerreloop" in Christopy, "Color Color Numerical Data Print" "Cro-color Color C
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       NODE #1"C4"K *1RT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           OR N=1 TO NN(7)11F 2<>SR(N) THEN MEXT ELSE 5145
RINT "CZNODE 6"C4-121-"C718 NOT A "CGMATER POINT"C7,"7030"180T0 5100
"NU(N)1P1=NR(P)1XF=NF(P)$NN(10)
F P=DD THEN 5157
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        PRINT CHR6(12);
2-0:11NPUT "CS-XENTER-2"C7 THE NOBE & OF A "C2COHBAT UNIT-CS-J-;Z
PRINT CHR6(12); THEN THEN NEXT ELSE 5175
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 RINT**CZNODE 0*C4*tZ;**CZIS NOT A COMBAT UNIT,**7030*18GTG 5100
=#+*N*(7)!P=*ND(S)!P!=*NU(S)!XF=*NF(S)*N*(10)
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    -011MPUT "CS"1ENTER"2"C7 THE NODE # OF A "C6WATER POINT"CS'12
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    DIN SD(WM(O)), WI(NM(O)), SP(WM(O)) IFI=32000
PRINT CHR6(12); "C3MOW CALCULATING ALL PATHS FOR FOR I=1 TO NM(O) ISB(I)=FIINEXT
SD(RT)=01MI(RT)=FIII=RT1M2=RT
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 F N1(K)<0 THEN 5275
F N1(K)>0 THEN 5280 ELSE N1(N2)=K!N2=K
11(K)=F1180T0 5280
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       SESSHORTEST DISTANCE SUBROUTINE
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       KZ=N8(1+1)!MZ=8B(1)!K3=N8(1)+1
IF K3>K2 THEN 5285
FOR 18=K3 TO K2
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   PRINT CHR$(12) # IRETURN
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  NG=11(1)121(1)=-111=XG
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      (=NT(18):N3=N2+AL(18)
IF N3>SD(K) THEN 5280
3P(K)=1:SD(K)=N3
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           #1(K)=#1(1):#1(1)=K
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            RINT CHR$(12);
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COST MATRIX IC(I,J). "7030"
                                                                                                                                                                                                                                                                                                                                                                        Y1=(INT(YM/FNR(YD))+1)$(FNR(YD));IF XN=0 OR YN=0 THEN 5572
Calculates Min. Value rounded down to most significant dimit
                                                                                                                                                                                                                                                                                                                                                     // Calculates Max. Value rounded up to most significant digit
XI=(INT(XM/FWR(XD))+1)#(FWR(XD))
                                                                                                                                                                                                                                                                         *###THIS SUBROUTINE COMPUTES ALL SCALING FACTORS FOR THE GRAPHS XI=01X2=01Y2=01XH=01FH=01FDR I=0 TO LST IHEN XH=X(I) 'DATA > MAX X
                                                                                                                                                                                                                                                                                                                                                                                                     72=(INT(YN/FNR(YD)))&(FNR(YD))!IF X2 OR Y2=0 THEN 5572
                                                                                                                                                                          BRETHIS SUBROUTINE CREATES THE COST MATRIX IC(S,T)
                                                                                                                                                                                                                                                                                                                 'DATA < HIN
                                                                                                                                                                                                                                                                                                                               MAX & MIN FOUND
                                                                                                                                                                                                                                                                                                                                                                                                                'Diff=Max-Min
                                                                                                                                                                                                                                                                                                                                             YD=0 THEN YD=YHIYN=0
                                                                                                                                                                                            ERASE ICIDIN IC(NN(7),NN(8)+1)
PRINT "NOW COMPUTING NEW TRANSPORTATION
FOR S=1 TO NN(7)
RT=8K(8):BOBGUB 5200
RT=8K(8):BOBGUB 5200
IC(8,T)=8D(8K(T))
                                                                                                                                                                                                                                                                                                                                                                                                                                                                        D1=DX#(410/(X1-X2));D2=DY#(350/(Y1-Y2))
                                                                                                                                                                                                                                                                                                                                                                                          X2=(INT(XN/FNR(XD)))&(FNR(XD))
                                                                                                                                                                                                                                                                                                                                                                                                                DX=FND(FML(X1))-FND(FML(X2))
                                                                                                                                                                                                                                                                                                                                                                                                                                  NL(Y1))-FND(FNL(Y2))
                                                                                                                                                                                                                                                                                                                                                                                                                                                   DX=10"(FND(FNL(X1-X2)-1))
DY=10"(FND(FNL(Y1-Y2)-1))
                                                                                                                                                                                                                                                                                           X(I)>XM THEN XM=X(I)
Y(I)>YM THEN YM=Y(I)
X(I)<XM THEN XM=X(I)
                                                                                                                                                                                                                                                                                                                        Y(I)<YN THEN YN=Y(I)
                                                                                                                                                                                     BOSUB 2000
```

1<F1 THEN 5230

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2469 '6847112 SUBMOUTINE PLOTS THE X8Y AXIS SCALES & LABELS THE AXIS SAND '684711 '197472770-730-7514 '1974727770-730-7514 '19747277770-730-7514 '197472777770-7514 '197472777770-7514 '197472777770-7514 '197472777770-7514 '197472777770-7514 '197472777770-7514 '197472777770-7514 '1974777770-7514 '197477770-7514 '19747277770-7514 '197477770-7514 '19747770-7514 '19747770-7514 '197472770-7514 '19747770-7514 '19747770-7514 '1974770-7514 '1974770-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-7514 '197470-751
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CACACA CACASTORN CONTROL

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'DO NOT PLOT ZERO VALUES
                                                                                                                                                                                                                                                                                                                                                                                                        F-11F-01N1=N+13ND=N+N
F-11F-01N1=N+13ND=01ST-01IT-01XI=1.7E+38
IF KY-1 THEN & ACOZ ELGE ERAGE ID.WF.1U.WU.ND.WR.ZP
IT KY-1 THEN & ACOZ ELGE ERAGE ID.WF.1U.WU.ND.WD.WR.YP.YP.
THEN ID(N) YNF(MD) INVIND, WULMD) WOLHD) WR(MD) ZP(MD) PRINT CHRE(12); WOU FINDING A STARTING ANSWER."K
                                                                                                                                                                                                                                                                                                                                                                                                                                                  'PRINT "IF JM IS ALREADY IN THE TREE, THEN GOTO 82"
IF ND(JM) <> 0 THEN 4078
"JS B NOT YE IN THE TREE"
"ABD THE ARC (ISJN)"

ZJ=TINR(JM)=MU(I)INU(I)=JMIND(JM)=IINF(JM)=HF
                                                                                                                                                               DIM ICCHM(7), WM(8)+1); DOS "ARYLDAD "+A$+"IC IC"
                                                                                                                                                                                                                                        *PRINT "SAVE IS AND ID TEMPORARILY IN IU"
FOR 1=1 TO MITU(I)=IS(I)!NEXT
FOR J=1 TO M-11D(J)=0(SK(J))!NEXTIID(N)=0(0)
FOR J=1 TO NIJH=J+NIIU(JH)=ID(J)!NEXT
*ROOT THE TREE AT NODE 1
                                                                                                                                                                                                                                                                                                         PRINT FIND THE MINIMUM ELIBIBLE CELL"
                                                                                                                                                                                                                                                                                                                                                           IF K >=L OR ID(J)=0 THEN 6052
--KiJS=JiZF=T
                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         86TD 6152
'"JS IS ALREADY IN THE TREE."
               XX=(X(1)-X2)&XC)+8X

) YY=(Y(1)-Y2)&YC)+77

IF YY-77<=0 THEN 5945

PLOT XX*YY*XX+5.78

HEXT
                                                                                                                                                                                                                                                                                                                                                                                               BELL THE STATE OF SERVICE
                                                                         PRINT CHR6(21)
                                                                                                                                                                                                                                                                                                                     J=012F=F12J=F
           FOR 1=0 TO LST
                                                                                                                                                                                                                                                                                                                                          F1 T0 K
                                                                                                                                                                                                                                                                                                                                                    K-IC(1,J)
```

XC=410/(X1-X2) YC=350/(Y1-Y2) PRINT \*\*B4\*F\*

ACCOUNT OF THE PROPERTY

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4100 K-WALLI D. O THEM 4100
4182 FOR 1-2 TO M
4182 FOR 1-2 TO M
4184 MRITI-WALKININKY 4100
4184 MRITI-WALKININKY 4100
4184 MRITI-WALKININKY 4100
4184 MRITI-WALKININKY 4100
4184 MRITI-WALKININKY ATTORNINKY
4194 CHRISTOL O THEM 4100
4204 CHRITICIAL IN THE THEE IS COMPLETE
4204 CHRITICIAL IN THE THEE IS COMPLETE
4205 CHRITICIAL IN THE THEE IS COMPLETE
4206 CHRITICIAL IN THE THEE IS COMPLETE
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4209 CHRITICIAL IN THE THEE IS COMPLETE
4200 CHRITICIAL IN THE THE THE THE THE THE THE THE THE
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CONTRACTOR CONTRACTOR STANDARDS CONTRACTOR CONTRACTOR

```
4.77 **REEF 18 AMD 18**
4.18 FOR 1-2 TO N
4.20 FOR 1-1 TO N 112 FOR 18 FOR
```

CHARLES CONTRACTOR PROPERTY STATEMENT BELLEVILLE CONTRACTOR CONTRACTOR

```
4440 LT. 1117
4440 TH. 1417
44
```

```
### CAND CATE

#### CA
```

```
'SET FLAG THAT COST MATRIX EXISTS
                                                                                                                                                                               T2=WF(K) IND(K)=KKINF(K)=T11T1=T2INR(K)=NU(KK)INU(KK)=K
                                                                                         IT=IT+1

@0T0 6280

COUTPUT OFTHAL BOLUTION

COUTPUT OFTHAL BOLUTION

'XD 18 THE TOTAL BISTANCE TRAVELED BY ALL UNITS

HM(12)=IT
'S
                                                           IF K <> 01 THEN 6548
RETURN FOR HEXT INTERATION
MUCL) -HR(K)
                                                                                10=X0-SL #TT
```

# APPENDIX VI

# TEST PROBLEM - OPERATION ORDER FOR OPERATION WINDUP

The following example operations order and example implementation problem was provided by the U.S. Army Engineer School, Ft. Belvoir, VA.

EOAC-G-010 S Practical Exercise

LESSON: Operation Windup

SPECIAL SITUATION NO. 5: Movement to Contact Planning

# General.

- 1. During the OPFOR attack into Western Europe you were wounded by receiving wood splinters in the index finger of your writing hand. Although you valiantly continued your efforts, by the end of the initial NATO offensive actions, you were medically evacuated to the southwestern United States. After a miraculous recovery you were assigned to the 27th Engineer Battalion, 27th Armored Division, during your period of outpatient convalescense.
- 2. As the OPFOR attack was repulsed and the NATO forces mounted sustained offensives, OPFOR leadership attempted a diversionary action to slow the rate of U.S. reinforcements to Europe. Several nuclear weapons were detonated in the vicinity of military bases in California. Numerous small airborne assaults were made into southwestern areas of the United States. (Critical supply facilities are located in the vicinity of AJO.) An OPFOR invasion of Mexico and subsequent link up with airborne forces was initiated.

#### Special Situation.

- 3. The bulk of U.S. forces have already been mobilized and are en route to the various east/west ports of embarkation. The only forces available to counter this invasion are:
- a. 27th Armored Division This regular army unit is located in Tucson at this time.
- b. 105th Infantry Division This reserve division has been forming in northern Arizona/Utah and is presently at 50% strength.
- c. 320th Infantry Brigade (Mech) This reserve brigade from western New Mexico was ready to deploy to Europe. It has been rerouted and is now beginning movement to Tucson.
- d. LX Corps This reserve corps consisting of a corps headquarters, support units, and some infantry brigades is now forming at Ft. Huachuca. The LX Corps Commander has been given the mission to locate and destroy the OPFOR forces; he and his staff are en route to Tucson now.
- 4. It is now 21 September 19\_\_. Prior to his departure from Ft. Huachuca the Corps Commander advised the CG, 27th Armored Division of the following:

- a. The 27th Armored Division would make the main effort against OPFOR forces. The 105th Infantry Division will screen the 27th Armored Division's northern flank. The 27th Armored Division would have to protect its own southern flank. To assist the Division with its mission (a very wide front) he was attaching the 320th Infantry Brigade.
- b. The operations overlay had been prepared earlier and was sent to the Division by Secure Western Union line.
  - c. Critical timings were given:
- (1) Within 12 hours forward elements of 320th Infantry Brigade to close on Tucson.
  - (2) Within 12 hours Division to cross line of departure.
- (3) Within 30 hours last elements of 320th Infantry Brigade to close on Tucson.
- (4) Within 48 hours Division to pass phase line TACO; or have encountered significant enemy resistance (Battalion +).
- (5) Within 96 hours Division to pass phase line PIZZA, or have encountered significant enemy resistance.
  - (6) No movement past PIZZA unless ordered by Corps Commander.
- d. The local authorities have provided the military with locations of possible airborne assaults (Overlay 1). Many OPFOR aircraft sorties have been sighted; smaller airborne assaults of platoon or less may have occurred.
- e. No actual sightings of the link up column have been reported; however, indications are that the airborne assault force must be resupplied 72-96 hours from now.
- 5. Based on the above guidance and the limited knowledge of OPFOR whereabouts, the CG, 27th Armored Division, decided upon a movement to contact, utilizing three brigades of the Division on line. The 320th Infantry Brigade (Mech) will form the reserve and will advance along the main road in sector (Highway 85).
  - a. The suggested Brigade Zones of action are shown on Overlay 1.
  - b. Each Brigade must provide its own covering force.
- c. Engineer advice is requested in view of LOC and water resupply problems

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- b. The operations overlay had been prepared earlier and was sent to the Division by Secure Western Union line.
  - c. Critical timings were given:

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- d. 5/22 Cavalry will screen the southern flank of the Division zone of action.
  - e. A draft Division OPORD is found at Annex A.
  - f. Additional considerations are found at Annex B.

# 6. Requirement:

- a. Acting as the ADE:
- (1) Prepare a written estimate for Division water requirements, to include proposed quantity resupply schedule (to which G4 will add unit designations and publish in ADMINO).
- (2) Prepare estimate for engineer effort required (discuss with monitor).
- (3) Write Task Organization Extract, Paragraph 2 and Paragraph 3 of the Engineer Annex (or sub-paragraph 3g if you don't feel an engineer annex is required).
  - b. Acting as the S3, 27th Engineer Battalion:
- (1) Write OPORD for Battalion (+) to include Task Organization, Paragraph 2, and Paragraph 3.
- (2) Prepare SOP checklist for desert operations. (What activities are affected by the desert environment, and how must we counter these effects.)
- (3) Prepare SOP Annex on composition and duties of a heavy rescue squad.
  - c. In your briefing:
    - (1) Discuss the tactics of crossing or passing through defiles.
    - (2) Cover all items listed in 6a and 6b.

Appendix 1 - 27th Armd Div OPORD (attached)

Appendix 2 - Additional Considerations (attached)

Appendix 3 - Overlay

Mapboard - 1:250,000 Arizona

# (CLASSIFICATION)

Copy 2 of 16 copies 27th Armd Div Tucson, Arizona (UL 6997) 21 Sept 19 DKL 28

# OPORD 09-01

Ref: Man, TUCSON and AJO, 1:250-000, Arizona sheets, 1962/69 editions.

Time Zone Used Throughout the Order: TANGO

# Task Org:

1st Bde	2d Bde	3d Bde	320th Sep Bde
5-91 Mech	5-92 Mech	5-94 <b>Me</b> ch	1-756 Mech
5-10 Arm	5-93 Mech	5-95 Mech	1-757 Mech
5-11 Arm	5-12 Arm	5-14 Arm	1-236 Arm
5-50 FA(DS)	5-13 Arm	5-15 Arm	Tp A, 1 Sqn, 320 Cav
(Engr TBA)	5-51 FA(DS)	5-53 FA(DS)	5104 Engr Co
	(Engr TBA)	(Engr TBA)	208th Spt Bn
Div Arty	Div Trp		DISCOM
5-53 FA	5-440 ADA		27th AG Co
9-600 FA	27th Engr En		27th Finance Co
	508th Engr (C	bt)	27th Maint Bn
5-22 Cav	5006 Engr Co (Dptk)		27th Med Bn
	5035 Engr Co (Pnl' Brg)		27th MP Cc
	3/5085 Engr Co (CSE)		27th S&T Bn
	· 27th Avn Co		
	27th Sig		

#### 1. SITUATION

# a. Enemy Forces

- (1) Airborne elements of suspected company size have been reported south and west of AJO. Smaller elements may be north and east of AJO.
- (2) Indications are that OPFOR will attack from southwest between TINAJAS ATLAS mountain and O'NEIL hills to link up with airborne assault forces
  - (3) Annex A, Intelligence

# (CLASSIFICATION)

# OPORD 09-01

Ref: Man, TUCSON and AJO, 1:250-000, Arizona sheets, 1962/69 editions.

Time Zone Used Throughout the Order: TANGO

## Task Org:

1st Bde	2d Bde	3d Bde	320th Sep Bde
5-91 Mech	5-92 Mech	5-94 Mech	1-756 Mech
5-10 Arm	5-93 Mech	5-95 Mech	1-757 <b>Me</b> ch
5-11 Arm	5-12 Arm	5-14 Arm	1-236 Arm
5-50 FA(DS)	5-13 Arm	5-15 Arm	Tp A, 1 Sqn, 320 Cav
(Engr TBA)	5-51 FA(DS)	5-53 FA(DS)	5104 Engr Co
_	(Engr TBA)	(Engr TBA)	208th Spt Bn
Div Arty	Div Trp		DISCOM
5-53 FA	5-440 ADA		27th AG Co
9-600 FA	27th Engr En		27th Finance Co
	508th Engr (Cbt)		27th Maint Bn
5-22 Cav	5006 Engr Co (Dptk)		27th Med Bn
	5035 Engr Co (Pnl! Brg)		27th MP Cc
	3/5085 Engr Co (CSE)		27th S&T Bn
	· 27th Avn Co		
	27th Sig		

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- (2) Indications are that OPFOR will attack from southwest between TINAJAS ATLAS mountain and O'NEIL hills to link up with airborne assault forces
  - (3) Annex A, Intelligence

# b. Friendly Forces

- (1) 7th TAF furnish close air spt to 27th Armd Div, priority to 2d Bde.
  - (2) U.S. Border Patrol units 8 and 9.
- c. Att and Det. 508th Engr Bn (Cbt) with separate engineer companies remain attached.
- 2. MISSION: The 27th Armd Div move at 212200 Sept 19 to locate and destroy OPFOR elements within zone of action and continue advance on order.

#### 3. EXECUTION

- a. Concept of Operation, Annex B Op Overlay
- (1) Manuever: 1st, 2d, and 3rd Bde conduct movement to contact in line over respective zones of action, providing own covering forces. 320th Inf Bde (Mech) is division reserve; division will hold at phase line PIZZA but will be prepared to continue advance on order.
- (2) Fires: Priority of air and artillary to 2d Bde. Annex C, Fire Spt, Nuclear fires will be emplaced only upon order of the division commander.
  - b. 1st Bde. Left forward brigade
  - c. 2d Bde. Center forward brigade
  - d. 3d Bde. Right forward brigade
  - e. 5-22 Cav. Screen division left flank
  - f. Arty: Annex C.
  - g. Engineer. TBA
  - h. DISCOM: Follow 1st Bde
  - 1. Res. 320th Infantry Brigade (Mech) (-)
  - j. Coordinating instructions
- (1) All units report locations of water immediately to division engineer
- (2) EEI: What is OPFOR location, desposition, composition, or capability?

- (3) Protection of civilian property to include elevated water tanks is essential.
  - (4) Operation exposure guide: RS-O
  - (5) Timings:
    - (a) Phase line TACO by 231000 September 19\_
    - (b) Phase line PIZZA by 251000 September 19
    - (c) Advance past phase one PIZZA on order
- 4. SERVICE SUPPORT: Annex E (Service Support)
- 5. COMMAND AND SIGNAL: Annex F (Communications-Electronic). CEOI 2-4.

Acknowledge.

DESICCATE MG

OFFICIAL

/s/Barrenland BARRENLAND

Annexes: A-Intelligence (Omitted)

B-Operation Overlay C-Fire Support (Omitted) D-Engineer (Omitted)

E-Service Support (Omitted)

F-CommunicationsOElectronics (Omitted)

Distribution: A

+ 508th Engr

(CLASSIFICATION)

#### ADDITIONAL CONSIDERATIONS

- 1. During September the soil is warm with a mean temperature above 47 degrees F. The soils are generally Aridisols-Argids and dry. Sun is out 12 hours a day and rain average is 1-2 inches during this month. Mean temperatures range from a daily low of 50 degrees to a high of 100 degrees F. with a mean of 80 degrees F. plus. The area is desert with some grazing and pastureland or shrubland. This has been an exceptionally dry month with no rain and all temperatures 20 degrees above normal. Visibility is unlimited, surface winds are negligible and the moon is the same as today's date.
- 2. Washes are trafficable to tracks but not to normal size wheels. Unimproved light duty roads are initially trafficable to tracks and wheels. Trails are passable to all tracks and wheeled vehicles up to 5 tons.
- 3. Light Data is the following:

BMNT	04:04	MOONRISE	
BMCT	04:40	MOONSET	_ <del></del>
SUNRISE	17:14		<del></del>
SUNSET	16:10	(CUR	RENT TIMES)
EECT	17:40	•	-
EENT	19:11		

- 4. The population is sparse, averaging less than 5 per square mile. AJO's population is between 7,000 and 10,000 and in addition to mining, is a summer resort area.
- 5. The division's units are organized at level 2 and are at full strength at that level.
- 6. The 27th Engineer Battalion has the following major equipment deadlines and shortages:

A	ITEM	SHORT	D/L	EVACUATED (Incl. in I	)/L)
APC		3	5	2	
CEV			1	No	
TRUCK	DUMP 5T	2	2	1	
TRUCK	UTI 1/4T	1	2	No	
LOADER			4	2	
TRACTO	R MED		1	No	
TRUCK	TRACTOR 10T		1	Yes	
TRANSP	ORTER END		1	No	
TRANSP	ORTER INT		3	1	

7. The division resupply is being replenished at a rate that provides only a three day basic load of POL, ammunition, rations and other classes of supply. Only repair parts available for the operation are the normally stocked PLL and ASL items. Class IV items are available.

ATTACHED TOWNSHIP TOWNSHIP

- 8. The division has been ordered to continue operating the five water points in the Santa Cruz river bed for incoming Corps units. Presently these water points are the 27th Engr Bn organic equipment.
- 9. The 508th Engineer Battalion has the following major equipment deadlines and shortages:

ITEM	SHORT	D/L	EVACUATED (Incl. in D/L)
TRUCK DUMP 5T	3	9	3
TRUCK UTI 1/4T		5	No
GRADER		1	No
LOADER	1	2	<b>1</b>

- 10. Water is scarce at this time of year. The division water supply is being furnished from five holes in the Santa Cruz River. Seepage into these open wells is slow and water can only be produced at 1,000 GPH from each water purification set 20 hours a day. The following reconnaissance information has been furnished:
- a. The large wells listed below can produce 1,000 GPH for 10-12 hours and then must set 12 hours before pumping can resume. Or these wells can sustain a continuous rate of 300 gallons per hour.

TULE	TL	4169
GARCIA	TL	4890
<b>JOHNSON</b>	UM	7320
PAPAGO	TL	8454
WHITE	UM	8993
DOBBS	VL	4748

- b. All other wells found on the map in zone produce 500 GPH, again, only for 10-12 hours a day, or sustain a continuous rate of 100 GPH. All wells average 400-500 feet in depth. These and large wells are available to the military.
- c. Tanks are not available, either being dry or reserved for civilian/cattle use.
- d. The AJO water supply system can provide the division 12,000 GPH with no distribution problems. A private well in AJO will supply water to the division medical battalion.

e. No other water source is available to the Division.

CAPE - RECEDED ON PROPERTY

- f. All rivers and washes are dry, sump holes produce no water except in the Santa Cruz River.
- il. The G4 desires to move the division main headquarters and support command to AJO as soon as practicable. Once the division forward elements have reached phase line TACO, he will plan to start movement of admin/log elements to the AJO area.

Appendix 2 to Special Situation 5 Operation Windup G-010-050

#### APPENDIX VII

# SUPPLEMENTAL WATER POINT SITE SELECTION CRITERIA

The following information was taken from reference [18], Appendix D, page 173 and Appendix F, page 175 and 176.

#### WATER SUPPLY CHECKLISTS

#### 1. Checklist For Water Reconnaissance

Information on the following items must be obtained and recorded:

- a. Quantity available.
- b. Quality.
  - (1) Color.
  - (2) Odor.
  - (3) Turbidity.
  - (4) Taste.
  - (5) Possible sources of pollution.
  - (6) Condition of vegetation.
  - (7) pH value.
  - (8) Chlorine demand.
  - (9) Test for chemical agents.
- c. Routes of communications.
  - (1) Condition of roads.
  - (2) Extent of road net.
  - (3) Traffic circulation.
- d. Site conditions.
  - (1) Cover and concealment.
  - (2) Possible aerial and artillery targets.
  - (3) Drainage.
  - (4) Bank conditions.
  - (5) Access roads and parking areas.
  - (6) Bivouac area for operators.
- c. Work estimate.

# 2. Checklist for Development of Water Points

The following list of questions is helpful in planning developments:

- a. Has the area been reconnoitered for a point requiring fewer improvements?
- b. Does the source yield enough clear water?
- c. Are all spillage areas, especially the loading area, well drained?
- d. Are all tanks and equipment level and off the ground?
- e. Are there enough storage tanks to handle peak loads?
- f. Can the treated water be safely and quickly distributed?
- g. Will dry points eliminate distribution problems?
  - h. Should a pipeline be used?
  - i. Is the water point well camouflaged?
- j. Is the treatment-equipment layout correct?
  - k. Are the water-point records adequate?
- I. Is the bivouac area adequate for personnel?
- m. Is latrine located at least 100 yards from and downhill from water point?
- n. Have shelters been provided for protection against the possible use of nuclear weapons?

#### **SOLOG AGREEMENT 125**

#### 1. Agreement

The Armies of the United States, United Kingdom, Canada and Australia agree to accept the criteria and standards set forth herein as the minimum potability standard for a safe emergency water supply intended for human consumption under field conditions.

#### 2. Criteria

- a. Short term field water consumption is consumption for 0—7 days.
- b. Long term field water consumption is consumption for periods in excess of seven days.
- c. Total daily consumption per man is considered to be 5 litres (1 imperial gallon or 5 US quarts). Under environmental conditions where water consumption substantially exceeds 5 liters per day, the tolerance levels should be proportionately reduced by the commander upon recommendation of his surgeon.
- d. At the individual level the only standards that can be applied are the bacteriological standard and the short term physical standard.
- e. At the unit level short term standards only can be applied.
- f. At Brigade, Combat Group or equivalent and rearward levels the short term standards apply for 0—7 days. Beyond this time frame, the long term standards apply.
- g. Where one of the Armies is unable to meet the standards prescribed herein, the other Armies participating in the agreement will be notified.

#### 3. Source

The water supply shall be obtained from the best available source and shall be rendered safe by acceptable treatment methods.

#### 4. Bacteriological Standards

a. Coliform Count. The most probable number of the coliform group of bacteria shall be

less than 1.0 per 100 ml of water. (Short and long term).

- b. Analysis. The method and analysis for coliform bacteria shall be that customary for the cognizant nation.
- c. Pollution. The presence of the coliform bacteria, including all organisms of the Coli-Aerogenes Group, shall be considered as indicating water pollution, other than BW Agents.

#### 5. Physical Standards

- a. Turbidity. For short term consumption water shall be reasonably clear. For long term consumption, the turbidity of water shall not exceed 5.0 mgms per litre. (silica scale).
- b. Taste and Odor. For short term consumption, water should be reasonably free from taste or odor due to hydrogen sulphide, phenols, or other chemical substances. For long term consumption, water should be free from taste or odor due to such substances both before and after disinfection.

#### 6. Chemical Standards

The methods of analysis for the following substances shall be as specified by cognizant nation.

#### (1) Short Term Standards

The maximum limits listed below are mandatory for emergency water supply for a period not exceeding seven days. (Asterisked standards are interim pending completion of more exacting studies.)

Arsenic (As) 2.0 mgm/1 Cyanides (incl Cyanogen

Chloride) 20.0 mgm/1
Mustard (Sulphur and

Nitrogen. 2.0 mgm/1\* Nerve Gas G (A) 0.1 mgm/1\*

(B) 0.05 mgm/1\* Nerve Gas (Vx) 0.005 mgm/1\*

#### (2) Long Term Standards

Nerve Gas G (A)

Magnesium (Mg)

Chloride

G (B)

(Vx)

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The limits listed below are preferable in water to be used continuously in excess of seven days. (Asterisked standards are interim pending completion of more studies.)

Arsenic 0.2 mgm/1

Cyanides (incl Cyanogen Chloride) 2.0 mgm/1

Mustard (Sulphur and Nitrogen) 2.0 mgm/1°

0.1 mgm/1\*

0.05 mgm/1\*

0.005 mgm/1\*

600.0 mgm/1

150.0 mgm/1

Color 50 units
Total Solids 1500.0 mgm /1

400.0 mgm/1

# 7. Radiological Standards (Gross Fission Products)

Sulphates (SO,)

a. For short term consumption, no absolute numerical standard is recommended or considered necessary. This is based on the conclusion that, if the external radiation hazard permits occupancy of the water point, the water suitable for consumption during occupancy not exceeding the one-week period.

b. For long term consumption, available information does not permit the establishment of a practical standard.

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